The Thesis Committee for Ahmad Alrashidan
Certifies that this is the approved version of the following thesis:

Forecasting Locations and Magnitudes of Pavement Loading Due to Development Activities

APPROVED BY
SUPERVISING COMMITTEE:

Supervisor:

____
Randy Machemehl

____
Zhanmin Zhang

Forecasting Locations and Magnitudes of Pavement Loading Due to Development Activities

by

Ahmad Alrashidan, B.S.

Thesis

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Science in Engineering

The University of Texas at Austin

December 2015

Dedication

To Najat Alhajeri and Jamal Alrashidan.

To my brothers and sisters.

Acknowledgements

I am grateful, appreciative and thankful for **Allah** for his long list of blessings, for giving me what I always ask for and for making me an ambitious person who always wants more. I also want to extend my genuine thanks and appreciation to:

Faisal Alsaif for being a great friend since day one and always being there whenever I needed someone to talk to. **Abdullah Alkharraz** for the long conversations and arguments that shaped the way I think. **Dr Alberto Arroyo** for being my mentor who believed in my potential and also for his continuous support. Dr Arroyo had a direct impact on my decision to pursue higher education and for that I am always thankful.

Carolina Baumanis for providing great tips and pieces of advice on how to be a better writer, without her help this thesis wouldn't be the same.

Kuwait University for funding my studies.

Moggan Motamed for helping me with new ideas and being supportive.

Jake Gutekunst for helping me at the beginning of the research

Dr Katie Kam, **Patrick Hughes**, **Rhonda Roundy** and **Matthew Reiter** for their help with acquiring data.

Dr Zhanming Zhang his comments in enriching this thesis.

Lastly, but most importantly, my supervisor **Dr Randy Machemehl** who has been nothing but kind and supportive for this work since the beginning, and also for giving me the chance to be his student.

This Acknowledgments also extend to my **UTSA** and **UT professor and colleagues**.

Abstract

Forecasting Locations and Magnitudes of Pavement Loading Due to Development Activities

Ahmad Alrashidan, M.S.E.

The University of Texas at Austin, 2015

Supervisor: Randy Machemehl

Forecasting future at-risk pavement locations can help prevent the expensive costs associated with rebuilding completely destroyed pavement. Optimizing the locations for preemptive maintenance results in better allocation of funds by cutting down total cost. Pavement maintenance makes up one of the largest expenditures for Departments of Transportation (DOTs) in most states, and historically over half of these funds have been spent on just Operations and Maintenance. Pavement lifespans depend on the design, maintenance, environmental influences, and traffic loading. Anticipating activities that cause increased truck loading can help prescribe preventative measures to reinforce pavement structures before they fail. This thesis focuses on

developing an ArcGIS-based tool that forecasts at-risk pavement failure locations by characterizing heavy truck trips. This study focuses on two truck travel patterns: 1) urban growth truck patterns and 2) oil and gas industry truck patterns. Truck trip generation tables were linked with forecasted routes using ArcGIS. By forecasting the locations of truck routes and loadings, the Early Warning System (EWS) tool will help officials make better estimates on where unexpected damages will occur in order to give officials time to take action. This thesis includes two models: 1) Oil and Gas industry in Austin TxDOT district. And 2) Urban Growth in Williamson County. The results of the models are maps showing locations of greatest pavement damages due to unusual truck traffic loading.

Table of Contents

List of Tables

List of Figures

CHAPTER 1: Introduction

Periodic pavement maintenance is a crucial part of all state DOT activities. In 2012, the US Department of Transportation spent more than 200 billion dollars on highways alone. (USDOT, 2014) Every year DOTs spend millions of dollars on highway maintenance projects, which play a huge role in the economy of the nation. The process of allocating maintenance efforts to specific projects is a well-planned process based upon periodic data collected to describe pavement conditions. Due to the immense quantity of paved roads (about 200,000 lane miles for TxDOT) condition data can only be updated rather infrequently (annually at best). Unusually heavy traffic loading caused by land development or re-development or mining can distort the expected pavement deterioration patterns sometimes causing unexpected pavement destruction. Costs to totally rebuild a destroyed pavement can easily be ten times the cost of strengthening the pavement adequately to handle the unexpected heavy loading. In order to save money and cut down on maintenance costs, pavements that experience unusually severe traffic loading should be identified. This work describes a tool that helps engineers know where unusually heavy traffic loading will occur so they can invest more maintenance funding to strengthen those pavements or at least be aware of the need to perform more than normal maintenance on those pavements.

The rate of pavement deterioration is dependent upon weather conditions, type of pavement and particularly traffic loading. Land development activities, sometimes called land use change activities including mining (petroleum resource recovery) often cause large concentrations of truck traffic loading frequently on minor roads that have weak pavement structures. The result is very accelerated pavement deterioration resulting in pavement destruction before maintenance authorities even realize what is happening. Savings of up to 90 percent of the cost of total pavement reconstruction can be achieved if sufficient strengthening to the existing pavement is made before it is destroyed. If the accelerated traffic loading occurs so rapidly that strengthening cannot be accomplished before major damage occurs, as is sometimes the case with mining, maintenance authorities could be aware of the need and could plan accordingly.

Closely studying the users of the roads and their patterns will generate a better understanding of where to focus maintenance attention. In comparison to cars, fully loaded truck-tractor configurations (18 wheelers) typically apply up to 3 equivalent single axles loads (ESALs) whereas a passenger car may apply less than 0.003 (EASLS). By their nature, trucks accelerate pavement deterioration and use pavement life up to a thousand times faster than cars. In 2002, nearly 16 billion tons (nearly 800 million fully loaded truck trips) of raw materials and finished goods were transported on the US freight system (USDOT, 2004). According to FHWA, from 1980 to 2008 lane-miles in US public roads increased only 8 percent to a total of approximately 8,518,000 lane-miles. On the other hand, Vehicle Miles Traveled (VMT) increased 51% during that same time (FHWA, 2008). The large increase in VMT on a network that has not been expanded or received appropriate preventive pavement reinforcement poses severe threats to the overall road network. Predicting the travel patterns of trucks can potentially reduce a large portion of maintenance costs.

Truck patterns related to the oil and gas industry and truck patterns related to urban growth are two examples of potentially unusual pavement wear patterns that can be predicted. Urban growth related trucks travel to and from retail-commercial land uses. Studying and following the path of this urban growth will give a better estimate on how to predict truck traffic flow. By knowing locations of establishments, the type of activity, and the area, it is possible to predict the trucks routes around the network. Oil and gas industry growth generates more oil/gas wells, therefore generating more truck activity. Studying the truck traffic related to managing wells will help to predict numbers of truck trips and their paths. Any rapid changes in oil and gas industry and urban growth will generate more truck flow, thus more severe pavement damage than anticipated over a short period of time.

High truck flow rates will typically generate heavy pavement loadings. Heavy loadings are generally less damaging to major highways (Interstate, US or State numbered routes) because they are designed to carry high truck traffic across states. The issue occurs when heavy loadings occur on rural/local streets or county highways like Farm to Market or Ranch to Market highways in Texas. Local streets are usually designed mainly to carry passenger cars and occasionally truck traffic. County highways were designed originally for farmers to transport agricultural products to markets in towns and cities so unexpected heavy truck traffic with heavy loadings poses severe effects, if it not completely destroying the pavement in some cases.

Current state of practice for maintenance differs from one state to another. Texas Department of Transportation (TxDOT) divides the present state of practice for maintenance into three categories, preventative maintenance, routine maintenance, and major maintenance. TxDOT defines preventative maintenance as any maintenance performed to “prevent major deterioration of the pavement” examples of that would include overlays or seal coats. On the other hand, major maintenance can be done to restore destroyed pavement including replacing the base as well as the wearing surface. However, preventative maintenance delays the need for major maintenance since its main purpose is to reduce major maintenance needs. The current planning process in each TxDOT district consists of each individual district developing an annual plan for maintenance projects by “analyzing historical quantities of work performed and the resulting level of service” (Holland, 2014). Using historical data can be inaccurate especially if land use changes are not captured in the previous year’s report and new projects (i.e. wells or residential developments) are being built in the existing year. Level of service takes into account the projected traffic but that also depends on variables like population and historical data as well. An Early Warning System can help capture those changes in land use and forecast their effects on pavement. This tool will be to help districts to be able to prioritize pavement maintenance for more effective use of tax dollars.

This thesis aims to generate a cost-effective tool that will help prevent losses by warning authorities about the critical road segments that are going to experience higher than usual truck traffic and loadings, which ultimately require preventive pavement reinforcement. This thesis will look into traffic loadings and routes, congestion and other negative impacts of truck traffic will not be included. In the next chapters, a literature review will provide an in depth review of previous studies that covered parts of the areas of this thesis. In the 3rd chapter, the methodology will discuss model and their truck trip generation tables with GIS data sources. Chapter 4 will have the results of the GIS model and analysis of the outputs.

CHAPTER 2: Literature Review

The current practice of maintaining pavement depends on annual reports of pavement condition and historical data that does not take into account unexpected traffic changes. Unexpected high truck traffic flow will not only damage pavements, but will produce significant economic impacts. American Transportation Research Institute (ATRI) analyzed GPS data gathered from various trucks moving along the US highways to estimate delay hours, idle truckers, and increased cost. ATRI reported that congestion "added over $9.2 billion in operational costs to the trucking industry in 2013" with the state of Texas being the 2nd highest state suffering from operational costs related to congestion with over a billion dollars (ATRI, 2014). Saving money is the second most important thing in pavement projects after safety. Cost effective binders and asphalt designs help engineers save money on materials. Optimizing schedules of importance for projects is another way to save money and time. Studies and research on pavement maintenance cost reduction have focused extensively on ways to spend less and get better products. Predicting truck travel patterns can serve as a potential solution to saving money on maintenance costs.

Preventive maintenance is usually a cost-effective procedure that is done to extend the pavement's life. According to Galehouse (2003) "preventive maintenance can extend pavement life an average of 5 to 10 years." However, preventive maintenance should be applied on the pavement at a specific time frame before failure in order to maximize effectiveness. The current state of practice for maintenance planning does not include provision for sudden, unexpected changes in typical traffic patterns. This is due to the deficiency of truck data which plays a major role in damaging pavements. The specific truck trip characteristics are usually related to the type of industry because the nature of a truck is to transport goods/products from or to destinations. Studying industries related to the growth of truck traffic in a certain area can help provide truck movement data. This type of data can be a solution to the lack of truck data needed to form recommendations for preventative maintenance.

2.1 Early studies: Characterizing pavement failure

The early studies quantifying the effect of traffic on pavement were conducted by The American Association of State Highway Officials (AASHO). AASHO study saw the need to develop standards to help build better roads. The lack of data for pavement design and the need to save money by optimizing design methods was the motivation behind this study. The AASHO pavement design method quantified pavement failure for the first time and introduced the equivalent axle concept. The equivalent axle concept provides an expression of the pavement damage caused by one pass of any axle weight compared to the damage caused by one pass of a chosen standard weight axle. An 18,000-pound single axle is often chosen as the standard. (Kawa et al 1998). With the findings from AASHO, this thesis can use equivalent single axles (ESALs) to describe truck impacts on pavement and by that also classify the levels of importance for future pavement maintenance projects.

2.2 Previous studies: Methods for Forecasting of Pavement Failure

Most previous research has used surveys to gather data about truck movements to build statistics-based forecasts. This pavement failure forecasting technique is ideal if data is abundant and easy to gather. However, if observations are scarce issues arise with these types of models. Spatially transferred data from like locations can be used, but it will not be accurate enough for pavement failure forecasting due to high numbers of variables that might affect the pavement failure. In the past, surveys have been used to acquire these types of data. However, surveys can be costly and time consuming, and updating survey data can be complicated if other factors were not accounted for in the first place.

Truck trip modeling can help predict the trips made by trucks and ultimately their impacts on the pavement. Transportation Research Board Special Report 288 (TRB SR288, 2007) discussed the need for improving travel-forecasting models because of the lack of treatment of commercial and freight data. The lack of available data on truck vehicle travel in general hampers the potential development of better models. For that reason, researchers have designed different methods to generate reliable data or incorporated existing data to predict future truck movements.

Truck traffic production and attraction GIS data can be used to as an alternative to actual truck data to develop truck flow prediction models. Tirado et al (2006) used a finite element model to calculate the pavement distress and then developed a graphical output using Visual Basic to be used on ArcView (GIS Software) to show the damages caused by super heavy loads on a specific route. Tirado introduced the use of GIS software to develop models that can help visualize locations of distress and rutting. However, ArcGIS has the power to be used not only as a visual tool to show outputs of other software, but also as an analysis tool. Another study that used GIS based data for pavement research, Osegueda et al. (1997), used overweight/oversize permit data in relationship with available GIS base maps from the TxDOT database to generate shortest paths between origins and destinations in Houston. The tool is easy to update with new data, TransCAD GIS software shows the maps, and the Dijkstra algorithm finds the shortest path between origins and destination. Osegueda et al. (1997) considered the issued overweight/oversize permits and investigated the condition of bridges (using the BRINSAP database) along the route of the permit. However, this study only considered the damage on specific bridge locations and did not consider predicting where the most damage will occur along routes. This thesis will use truck trip generation tables and GIS data to characterize pavement damage in terms of ESAL loadings along routes. This alternative approach can save money and time in comparison to traditional surveying techniques. Moreover, ESAL data is easily accessible and updated frequently, therefore a model can be built for recurrent use. Previous studies about truck trips related to urban growth and land use changes will be discussed first followed by truck trips related to the Oil and Gas Industry.

2.3 Previous Studies: Characterizing Urban Area Related Truck Trips

Urban growth leads to land use changes that are facilitated by truck traffic. These changes are desirably captured in transportation plans that are intended to improve accessibility or mobility. Some statewide plans identify major truck corridors and provide instructions on how to predict and prepare for truck impacts. In the case of smaller developments, the concerns for developers are usually accessibility and/or mobility of the site. Research concerning land use changes and urban growth has shown little effort in how to predict the effects of the additional truck movements that are associated with urban growth.

Traditionally, the four-step demand estimation model has been used to create transportation infrastructure plans. Trip generation is the first step in the traditional four-step transportation-planning model. This includes tables consisting of trip ends produced and attracted by each development or zone. Trip distribution, the next step in the model, uses trip ends as origins and destinations connecting trip ends to make trips. The trip distribution step generates an origin-destination (O-D) matrix characterizing the trips between zones. The third step is mode choice, which can be skipped when modeling truck trips because there is only one mode option. The final step in the four-step model is traffic assignment or route choice, which in most cases will be the shortest distance path. This step is crucial to maintenance and loss prevention planning because it determines which routes the trucks are going to take and which routes will most likely suffer most damage.

Most planning methods for smaller urban areas and rural areas have assumed that trucks are only a small fraction of the traffic, however studies show that trucks make up a significant portion and should not be ignored. Cambridge Systematics (2004) used the Freight Analysis Framework data to analyze congestion in urban and rural areas, with and without truck data, and found that excluding truck data would only show congestion in urban areas and not any of the congestion present in rural areas. This shows that trucks have a direct impact on congestion in rural areas. Another study conducted by Cambridge Systematics (2005) used weigh-in-motion (WIM) data from 55 sites in California and reported that on a single weekday the percent of trucks composes 4% to 14% of the traffic flow. Moreover, the most congested time of day is from 8am to 5pm at which time the average truck flow reaches nearly 10%. Given the fact that trucks are on average three times larger than a passenger car, 10% of the flow might take up to a 30% of the capacity of the streets. Additionally, Motuba (2009) showed that trucks are a significant fraction of the traffic in small to medium sized urban areas and can cause congestion, therefore requiring careful attention during planning stages. These studies have highlighted the importance of considering truck traffic in small to medium sized urban areas as well as rural areas. Planners should consider truck traffic as a significant portion of the traffic in all areas. This thesis considers truck trip traffic as the primary indicator for future damage because trucks accelerate pavement deterioration, and because they make up a significant portion of the traffic as well.

Many studies have created Truck Trip Generation Tables (TTGTs) for various cities that provide the rate for truck flow in and out of a development by various variables, such as trip purpose or size of establishment. The Institute of Transportation Engineering (ITE) Trip Generation Manual is widely used to forecast traffic flow numbers. However, ITE reported trip rates pay little attention to truck traffic flow. This is why most research studies resort to generating tables based on data and regression statistics. Tadi and Balbach (1994) developed TTGTs based on regression statistics for nonresidential land uses in the city of Fontana. In their study, they gathered data from 21 sites by both manual and machine counts and generated tables based on weekday, morning peak hour, afternoon peak hour, and site peak hour. The variables in this study were square feet of building area of warehouse, industrial, and industrial park developments. Jaller et al (2014) used area size of developments in New York City to create Freight Trip Generation (FTG) tables from regression statistics. The findings showed that type of employment and area-size had a strong relationship in determination of freight trips. The study mainly aimed to generate FTG tables that use land area as the variable to forecast trips, however the model lacks flexibility because it only works with datasets that include area size. Another study that took into account categories not in the ITE Manual was Neustaedter et al (2003), which developed City of Fontana TTGTs based on regression analysis of three independent variables. The study surveyed 34 locations and divided land use classifications into eight categories. Three out of the eight categories: truck sales, used truck lots, and truck stops, are not included in the ITE Manual. Number of employees, gross building area, and acres were the three independent variables in the study. In some developments, the operational truck traffic flow is not necessarily independent of the area size, as shown by McCormack et al (2010). Their study focuses on 8 grocery stores in the Seattle area and their relationship to truck traffic flow. The report developed TTGTs based on data collected through phone interviews and manual traffic counts. The study did not find that grocery store variation in size led to more or less truck traffic. However, a reason for that could be that the sizes of the grocery stores chosen in this study were very close to each other. This study will apply truck trip data acquired from previous studies on different types of development.

2.4 Previous Studies: Characterizing Oil and Gas Industry Related Truck Trips:

The oil and gas industry plays a vital role in the economy of Texas and the associated effects of truck traffic impact the road network tremendously. In 2014, there were more than 1 million active wells in the United States and more than ¼ of those wells are located in Texas (Kelso, 2014). This puts a huge burden on the transportation network in Texas as it provides oil for most of the surrounding states and its own fast growing population.

The effect of unexpected loading has been extensively studied in the area of bridge and road structures, but recently this concept has received more attention for pavement management. The majority of the studies on pavement management are focused on how to deal with overloading by improving asphalt material. The Utah Department of Transportation (UDOT) developed a manual for pavement management to provide a cost effective solution for pavement rehabilitation design. Their approach is evaluating pavement prior to rehabilitation. An enormous strategy between scheduling, organizing and designing pavements has been studied and a cost effective solution for each pavement condition was proposed. This report focuses on solution not causation. Another recent study conducted by Sianipar (2014) examined the influence of traffic growth and overload on road life-cycle. They found that the biggest cause of life-performance decrease is overload, and that the effects are non-linear. This shows that overloading the pavements can cause severe damages and cannot be predicted linearly. The rate of damages can be faster than the rate of overloading.

Several studies evaluated the expected damage and cost caused by oil & gas development activities. TxDOT has started to evaluate short-term and long-term impacts of energy related activities on the state’s transportation infrastructure. Moreover, Quiroga et al (2012) provided a comprehensive document on the impacts, needs, and strategies for TxDOT, including the effects of horizontal well activity. They estimated a typical rural road would lose 39% of its life after one year of 100 horizontal gas wells. Considering re-fracking the wells every five years, they estimated the pavement would reach the end of its life before ten years. Abramzon (2014) provided a similar technical report for the Pennsylvania Department of Transportation (PennDOT). The report revealed the per-well cost depends linearly on the number of truck trips and the length of the truck trip. If the average one-way trip deceases by half, the per-well fee could be reduced by 50%. They recommend a comprehensive design policy that motivates companies to minimize activities that damage the roads. Reimer (2014) developed a framework for the oil & gas industry to optimize their transportation activities. This study develops an integrated framework for the state’s Department of Transportation to prioritize road segments for maintenance. However, none of these studies have recommended a way to determine exact location for these types of damages.

Different studies addressed the problem of hydraulic fracturing (fracking) in relation to various variables, however Prozzi (2011) addressed the fracking problem and its impact on transportation infrastructure by using GIS-based data to find the shortest route that trucks would take. Prozzi discussed that there is an increasing demand on the Texas infrastructure, especially the rural roads that are used for moving equipment into sites, since 30% of the US natural gas and 19% of the US oil is produced in Texas. In her study, she located active gas wells and assumed the closest disposal well was the one in service. The routes between the truck's origins and destinations were generated through Google Maps. Vehicles Miles of Travel (VMT) was the variable used to emphasize the percentage of truck trips that traveled on rural roads. In her findings, 30% of truck trips moving water to disposal wells were using local streets.

In the next chapters, the methodology in this thesis is developed based on current research gaps. One of those gaps is linking the GIS source with Truck Trip Generation to forecast locations of heavy loadings. Traditionally, statistical estimations predict truck traffic impacts. However, this thesis will use shortest path routes to forecast truck impacts. Two case studies will be built based on the methodology and their analysis and results will be discussed after.

CHAPTER 3: Methodology

The methodology of this thesis will be built on 3 steps, generating Truck Trip Generation Tables based on analyzing previous studies. Gathering GIS locations of trips associated with land use changes, which will generate unexpected truck trips added to the network. The last step is to link TTGTs to GIS data based on ArcGIS to forecast these trips shortest routes with their loadings. The output of the model is a map that shows locations of total loading values on each segments of the network.

3.1 Urban Growth and Land Use Changes:

Urban growth usually generates rapid land use changes. These changes affect transportation networks as they cause more traffic to use existing infrastructure. Capturing those land use changes when planning helps in planning better arrangements for pavement service life. Building a brick plant in a rural area can and will generate heavy truck traffic that generally has high loadings as well. These loadings can cause the pavement to fail before the end of its expected service life. DOT districts end up paying millions of dollars to reconstruct failed pavements while it would be more cost effective if sufficient reinforcements were made on the pavement. These land use changes can be tracked and their effects on the pavement can be predicted. If the district knows where the brick plant is going to be built, the size of the plant, the origins and destinations for the associated truck traffic, it could easily predict future damages on the routes. The method described in this thesis uses GIS locations of future land use, type of establishments, and establishment area sizes.

The first step in the traditional four-step transportation planning model is trip generation. Depending on the data source, an estimate of how many trucks are going in and out of each establishment can be generated. Based on previous studies, NCHRP 298 reported that the general practice to predict trucks generated by a certain land use is to use independent variables like square feet of land used or employment numbers to generate establishment based truck trips. Moreover, Jaller et al (2014) studied 1890 models of trip rates and regression models for production and attraction and found 41.59% of these models used area, 29.89% used employment, and 14.71% used establishment type. While establishment type can serve as a predictor, using it could lead to errors because it over generalizes the number of trips. For example, an establishment-based trip model will give the same number of trucks for a grocery store regardless of the size. These results could be misleading because grocery stores can vary highly in size, which ultimately leads to variation in truck trip rates as well.

Reliable truck trip forecasting uses an equation not only limited to area, employment, or establishment type but also includes number of days that the establishment experiences truck traffic.

Figure 1: ESAL ratios during a week. Source: Cambridge Systematics 2005.

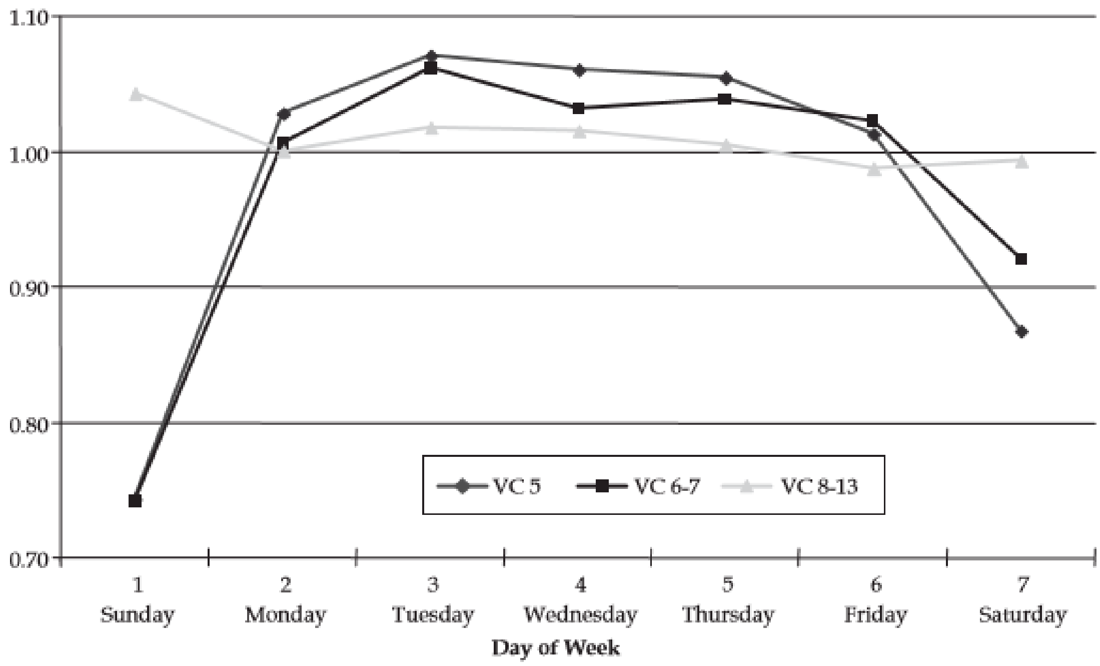
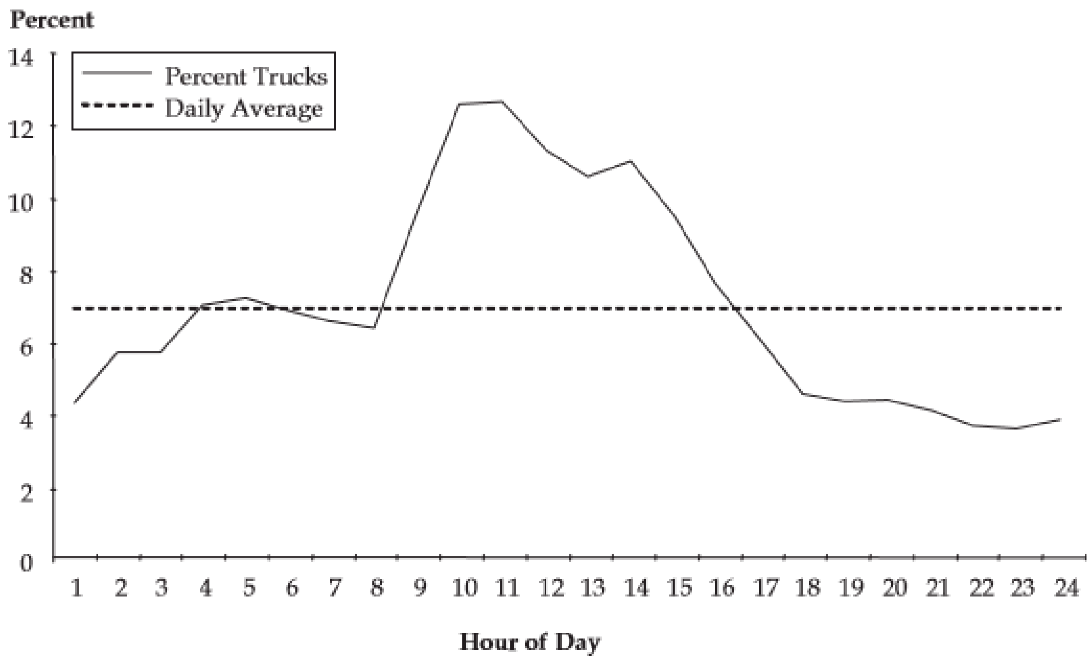


Figure 1 shows higher daily ESAL ratios from Monday to Friday, which implies that days of the week will generate different truck traffic rates. Tadi and Balbach (1994) built their truck trip rates on the fact that weekdays truck traffic rates are different than weekend rates. They studied truck traffic rates on a weekday and weekend basis, and included peak hour rates for AM and PM of weekdays.

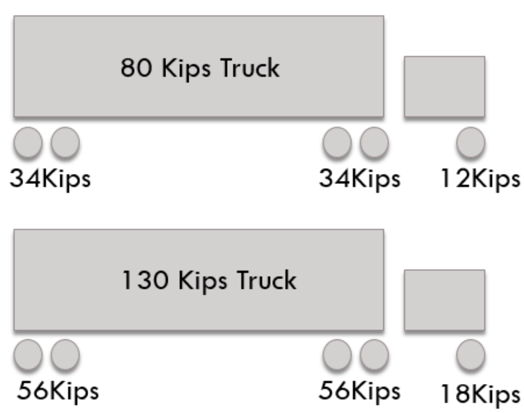
Figure 2: Truck percent of traffic through 24 hours of the day. Source: Cambridge Systematics 2005.



Time of day plays another major role in determining traffic trips rates. Figure 2 shows most of the truck traffic travels during business hours. This fact may add another variable to the list of variables affecting truck trip generation tables. The last factor we consider in this thesis is truck configuration. The word truck has a large definition that might include any type of vehicle that is used to transfer products and goods. A better understanding of the degree of damage can be achieved by answering the question: what *type* of truck can be most damaging? According to FHWA (2000) more than 42% of the trucks in the nation are 3-S2 trucks. This makes it the most common truck types in the United States. The 3-S2 truck configuration is shown in Figure 3. An SU2 truck is the second most common type making up more than 35% of the trucks on the road. An SU2 truck is a single unit with 2 axles. The rest of the configuration types are divided among more than nine different types and can be considered negligible due to their rare existence. The variables used for establishment-based Truck Trip Generation Tables are the following:

- Size of Establishment (acres, square footage);
- Employment (number of employees in each establishment);
- Type of Establishment (rates can be generated on type of establishment only);
- Days of activity (days that the establishment will be receiving/sending trucks);
- Hours of activity (hours of day that that the establishment will be receiving/sending trucks); and
- Truck Configuration (type of trucks).

Figure 3: 3-S2 Truck Configuration and ESAL loading.



ESALs can provide a better estimate for the damage a single pass of a truck on specific pavement can cause. As discussed earlier, ESALs describe the damage a specific axle load causes to the pavement, compared to a single axle load of 18Kip. According to FHWA standards for commercial vehicle weight, the maximum gross vehicle weight is 80Kips (FHWA, 2013). Figure 3 shows a likely breakdown of 80Kip and 130Kip gross weights on the axles. Assuming rigid pavement and structural number of two based on AASHTO design methods, Table 1 show ESAL value example calculations based on the truck weight.

Table 1: ESAL Number Calculation for Different Weights.

ESAL Number Configuration						
Purpose	**Full Weights**	**Single Axle (Kips)**		**2 Tandem Axles (Kips)**		**ESAL (Value)**
Max. Legal limit	80,000	12	0.229	34	2.22	2.449
Heavy Trucks	130,000	18	1.49	56	8.1	9.59

In general, models are with specific variables in mind and exclude some negligible variables. In this thesis, we are mainly concerned with trucks that may cause significant pavement damage. In this model, these truck can travel at any time of the day causing congestion and pavement related issues. Previous research tried to minimize congestion caused by these trips by suggesting scheduled deliveries at times outside of the peak hour traffic. However, this type of schedule will not be included in this thesis and travel time of the day will not be a concern.

3.1.1 Urban Model Truck Trip Generation Tables:

Truck traffic related to urban land developments can be mainly categorized into two phases, construction and production traffic. Construction traffic refers to the truck traffic transporting construction materials and equipment in and out of the site. Because the small size of this traffic in relation to production, very few studies considered studying this activity to make travel predictions. Construction traffic varies highly from project to project, not only because of the size of the establishment or the amount of materials, but also because of the funding available for the project. A time-sensitive project could have more funding invested to finish the project in less time. An effect of doing more work in less time generally generates more truck traffic. However, in this thesis these variables are not considered. Truck traffic for construction purposes can be sufficiently treated by dividing it into two sub-categories: residential developments and all other developments. According to the US 2010 Census, an average lot size for a new single-family house sold in the United States is 17,590 square feet. To maintain conservative predictions, this study uses 15,000 square feet in determining house lot area sizes. However, different areas might have different lot sizes, this can be done on a case by case basis.

Construction TTGTs will be built based on three assumptions:

1) An average house requires two 3-S2 trucks to get the concrete/timber and equipment needed (If an average lot is 15,000 square feet, then every 7,500 square feet of lot requires one truck)
2) One truck will be required per 1000 square feet of building gross floor area for any other development (i.e., industrial, manufacturing, and warehouses) since most of these establishments will have concrete slab and steel hanger systems,
3) Construction traffic will be studied in a one-year period, meaning that at least every year the construction traffic model should be updated.

In this thesis, the theory of “it is safe to overestimate rather than underestimate” was followed in these assumptions and other assumptions that will be discussed later. Table 2 shows the truck trip generation for construction traffic that was built on previous assumptions.

Various studies projected future production truck traffic for land-use changes. Production is easier to predict based on consistency of travel patterns or repetitions of some deliveries to or from the site. Also, Production traffic continues to be observed at least for the first 20 years or when the establishment changes the business type, which affects the flow of trucks greatly. Production TTGTs rates were gathered from three studies that use the same variable to predict the trips: trucks rates per 1000 square feet of establishment area size. Tadi and Balbach (1994) predicted the land use of “Heavy Industrial” trips to have 4, 5, and 6+ axle trucks traffic of 0.38 per 1000 square feet. In Boston, Nixon (1993) studied all 6+ axel truck traffic by land-use type and generated the tables based on trips per 1000 square feet. His rates for manufacturing sites, warehouses, and residential production activity were respectively 0.35, 0.44, and 0.11. McCormack et al (2010) results yielded 18 truck trips per day on a weekday, which this study assumed to be the peak as well. Taking the value of 18 trucks per day and dividing it by the average grocery store size in the Seattle area will give a rate of 0.51 trips per day per 1000 square feet. Table 3 shows the truck trip generation for production traffic.

Table 2: Construction Truck Trip Generation.

Construction Activity Rates			
Purpose	**One truck per**	**ESAL (Value)**	**ESALs/Trip**
All Purposes	1,000 SF	2.449	2.449
Residential	7,500 SF	2.449	2.449

Table 3: Production Truck Trip Generation.

Production Activity Rates			
Purpose	**Volume**		**Source**
Industrial	0.38	/1000 SF	Tadi 1994
Grocery store	0.51	/1000 SF	McCormack 2010
Manufacturing	0.35	/1000 SF	Boston 1992
Warehouse	0.44	/1000 SF	Boston 1992
Residential	0.011	/1000 SF	Boston 1992

3.1.2 GIS Mapping Tool:

The TTGTs determine the truck trips associated with each land development, but they do not tell us any route information. The goal here is to predict the routes that trucks will follow with GIS and connect their impacts on the pavement determined by the TTGTs to these routes. This step depends strongly on the GIS data source, specifically the locations of the developments and the variables associated with it. For this thesis, the main variable chosen was volume in terms of 1000 SF area size. Connecting the locations of developments to their origins or destinations can be complex. There are a lot of different locations that are associated with sending or receiving trucks to a certain development. For example, a commercial warehouse will have truck traffic from/to the regional distribution center and different customer locations, which are difficult to predict. Other possible origins/destinations for other facilities could be much more challenging to predict.

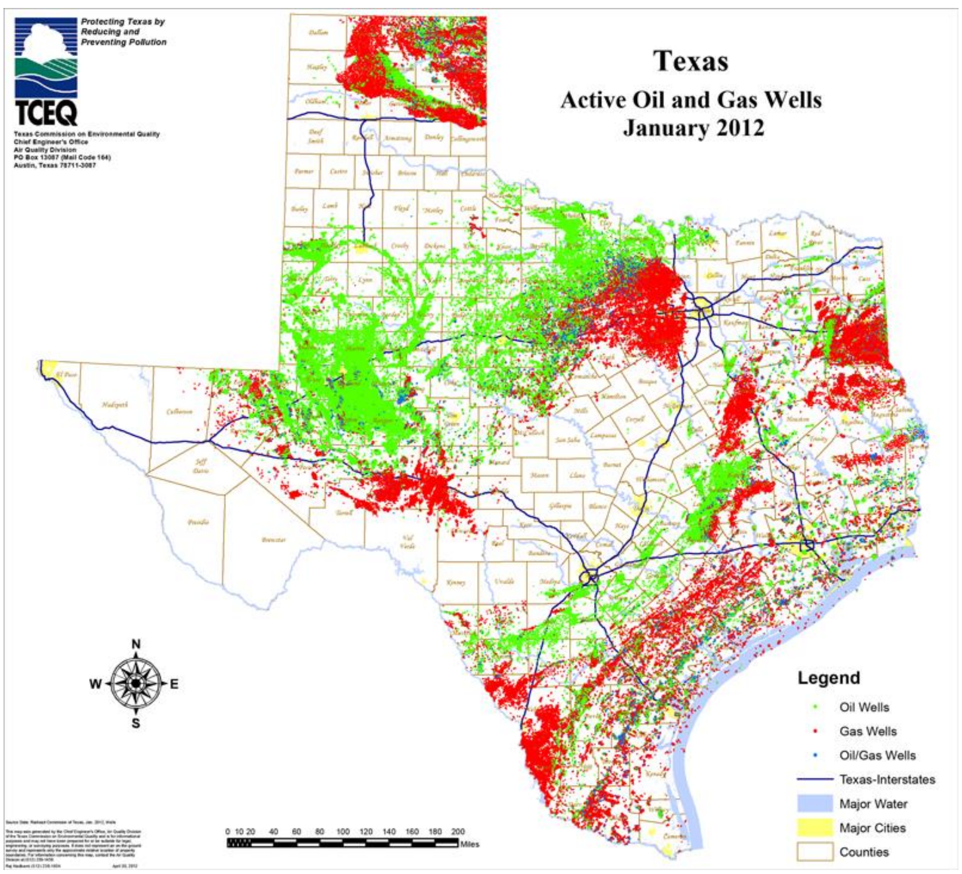
ArcGIS will be the GIS mapping tool used in this study to read GIS data, predict routes, and calculate damages based on ESAL values. In this case, shapefiles, a file format used by ArcGIS, are the ideal file format as it is the file format that ArcGIS employs to manage the base map and associated attribute information. However, excel files with longitudes and latitudes can be exported and used in ArcGIS and will work as well. The ArcGIS Network Analyst extension calculates the shortest distance between an origin and destination using the Djikstra algorithm. This tool can also find the shortest path in terms of time of travel; in this thesis the focus will only be on the shortest path travelled in terms of distance. Network Analyst has a variety of different tools that cater to a myriad of complex routing problems that a user might be looking to solve. One of these tools is Closest Facility, which solves the shortest path between an origin and destination. However, the tool uses two names for these origin/destination locations: Facility and Incident. In this tool, every incident needs to be connected to a facility, but not every facility must be connected to an incident. An example of that would be locations of grocery store incidents and distribution centers as the facilities. For each grocery incident a route connecting the distribution center with it will be generated. However, some distribution centers will not be used in the analysis as they might not be needed. The reason behind using this particular tool is that the scope of this thesis is focused on land use changes that are going to be served by different locations. The land-use change locations (oil and gas wells, a new residential development) will be the “incident” and the cause of truck traffic to travel from the facilities to serve the needs of the “incidents”, however not every facility will be connected to an “incident” in this case. Trucks traveling to service the needs of these land-use changes will generate loads that are not expected, and must be predicted.

GIS-based locations are linked with the current road network, and depending on the development type, will generally generate two types of traffic: construction and operation. The model will have a map for each type of traffic. Forecasting the truck routes should be done based on an origin/destination methodology, however at this point, only one end of the route is known – the land development location. The other end of the route is hard to predict, because trucks can travel in many different directions without the ability of the model to predict these routes. However, trucks usually travel on highways for longer trips, and generally heavy trucks tend to travel longer distances to transport mass products. Connecting the land development location to the nearest state highway is a good representation of what happens. Additionally, it is an ideal choice for travel because state highways are usually designed and maintained to handle high truck traffic. Additionally, choosing a state highway route captures the local streets that are used as access routes for trucks related to land development. These streets are the most likely to be destroyed because local streets are built and maintained with the assumption that they will experience very low truck volumes in most cases, which leads to undesirable consequences in the case of an unexpected increase in truck volumes. The state highways that are going to be considered as origins and destinations are: Interstate highways, State Highways, and US highways (IH, SH, and US). Another suggestion for GIS analysis of other models, the prediction can be done based on a buffer zone around the developments with a radius of a specific distance. Based on population or employment working as traffic magnets, the assignment of truck routes will be on the corridors with cardinal directions traveling in the heavy population or employment direction. Depending on the truck activity data it could also be seen as the data of origins or destinations of potential truck movements that could be used to produce truck routes

3.2 Oil and Gas Industry Growth:

In Texas, oil and gas well locations are typically in West Texas or in the Gulf of Mexico, approximately 200 miles away from shore. Figure 4 shows that the locations of active oil and gas wells. Note that most of them are not close to a major highway.

Figure 4: Active Oil and Gas Wells in Texas. Source: TCEQ 2014.



Constructing and operating these wells requires transportation of equipment, water, and other products. The recent boom in oil and gas unconventional shale plays requires that these products be transported by a large number of very heavy trucks, which were probably not expected during pavement design. Widespread use of hydraulic fracturing, or fracking, has generated more heavy trucks in comparison to traditional drilling activities. This is specifically due to the extremely high need for water related to each well construction and production activity. According to the US Department of Energy (2013), up to 95 percent of new wells being drilled are hydraulically fractured. In the United States, these wells make up 43 percent oil and 57 percent natural gas production on average. The highly repetitive trips and loadings associated with servicing the wells are usually concentrated on low volume roads that have thin pavement structures. Such loadings can severely damage, or even destroy the pavement. These trips are providing equipment, supplying water, disposing of water, and carrying aggregates and chemicals to the site of each oil well.

3.2.1 Oil and Gas Model Truck Trip Generation Tables:

The main element transported to and from fracked wells during construction and production is water. The water volumes moved per well were determined from information obtained from fracfocus.org, a voluntary disclosure database that gives details of hydraulic fracturing in the United States. This site provides information about water volume, date of well drilling, and the percentage by weight of fracking fluids which varies when involving water, sand, and standard chemicals. For this study, a sample of data from three counties in Texas, Caldwell, Bastrop, and Lee, was selected and extracted. Locations and approval dates of oil drilling permits and active saltwater disposal well information was gathered from the Railroad Commission of Texas (RRC).

The sample data extracted from RRC included information on 21 oil wells. Thus, the dates for which the permit was submitted and approved could be found. The start date for drilling was also noted for this study. The average expected time upon approval to start of drilling is around 65 days, while it only takes 13 days on average for constructing an oil well. With respect to only horizontal fracking wells, the largest well may require over 9,232,230 gallons of water during its life. Clearly, on the average more water is required for horizontal fracking at 5,943,105 gallons per well whereas vertical drilling requires about 1,389,803 gallons of water. In Texas, vertical drilling is not as common as fracking. For this study, the truck traffic associated with conventional vertical drilling methods is excluded. The analysis of the days of the construction period of the sample is in Figure 5.

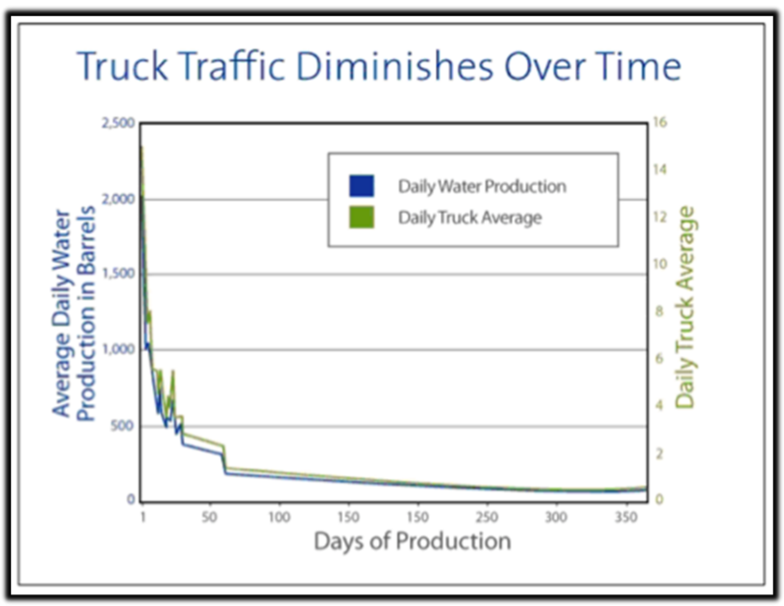
Table 4:Horizontal Fracking Wells Data.

Horizontal Fracking Wells								
API No.	Water Vol (gal)	Sand %	Water %	Approved	Drill Start	Drill Finish	Wait	Constr
28732619	7,820,526	13.58	82.58	12/4/2013	1/22/2014	1/29/2014	49	7
28732615	6,503,834	11.35	83.72	11/8/2013	2/18/2014	2/25/2014	102	7
28732621	6,020,994	12.78	83.05	12/13/2013	3/6/2014	3/13/2014	83	7
28732620	5,841,912	14.18	82.77	12/13/2013	3/6/2014	3/13/2014	83	7
28732617	7,264,716	13.27	86.71	2/26/2014	3/30/2014	4/5/2014	32	6
28732623	8,160,396	17.27	81.21	2/27/2014	4/5/2014	4/11/2014	37	6
28732628	7,243,404	13.93	76.96	3/6/2014	4/11/2014	7/16/2014	36	96
28732630	4,247,444	11.18	87.83	3/11/2014	4/16/2014	4/19/2014	36	3
28732635	5,382,036	11.22	87.69	4/9/2014	5/14/2014	5/17/2014	35	3
28732636	6,162,986	11.96	86.28	4/16/2014	5/27/2014	6/8/2014	41	12
28732626	4,544,240	11.64	86.62	2/28/2014	5/27/2014	6/8/2014	88	12
28732629	2,852,620	17.16	81.96	3/8/2014	6/10/2014	7/18/2014	94	38
28732616	4,210,796	14.41	83.51	4/4/2014	6/18/2014	6/25/2014	75	7
28732634	6,780,786	14.30	83.62	4/4/2014	6/18/2014	6/25/2014	75	7
28732641	7,037,294	12.12	84.97	5/6/2014	7/7/2014	7/14/2014	62	7
28732640	5,300,068	12.87	85.29	5/6/2014	7/7/2014	7/14/2014	62	7
28732632	9,232,230	11.65	89.44	3/15/2014	7/15/2014	7/21/2014	122	6
28732643	2,197,202	14.31	80.19	5/29/2014	7/17/2014	7/18/2014	49	1
28732646	5,286,204	13.21	83.83	6/9/2014	8/4/2014	8/8/2014	56	4
28732647	5,293,196	14.85	83.35	6/9/2014	8/15/2014	8/20/2014	67	5
28732646	7,140,462	11.29	84.94	6/9/2014	8/24/2014	9/10/2014	76	17
28732649	6,224,960	11.44	84.83	6/9/2014	8/24/2014	9/10/2014	76	17
Average=	**5,943,105**	**13.18**	**84.15**		Average Days		**65**	**13**

The quantity of sand used in fracking for each oil well must also be considered. According to the sample given by the RRC, only 13.18% of the total injected fluid mass is sand. Given the amount an average truck hauls, the amounts of water and sand supported during transport could be determined. Average hauling trucks can hold 20 cubic yard of sand. Therefore, 13.18% of 5,943,105 gallons is 3,878 cubic yards. Dividing that by 20 gives an estimated 194 trucks transporting sand in and out of wells. After finding the weight of the materials being carried, the number of trucks necessary for the process of water supply and disposal can be calculated. This number is estimated for the entire oil well completion. Quantities of water and sand are given in Table 4, which shows the average water volume utilized for horizontal drilling is shown. Given the fact that most water hauling trucks have a 4000 gallons' capacity, over 1,486 trucks are needed to transport water for a horizontal well.

Generally, flow back of disposed water is about 20-50 percent of the total volume used in the injection process for fracking. For the purpose of this study, a near worst case assumption of a 40 percent flow back volume during the construction phase was used. After the initial oil well completion, lots of saltwater backflows with the oil or gas being fracked. This saltwater is mostly disposed of after the rate of flow back decreases. At that point, the saltwater is transported off site by use of trucks. Figure 5 illustrates how the average daily truck traffic decreases after the initial two weeks of drilling.

Figure 5: Well Production Truck Traffic. Source: Prozzi 2011.



The highest daily truck traffic experienced after 20 days of drilling would be up to 2-3 trips. Transporting gravel is another small, yet relative element to consider. Gravel is important for its use to building access roads where rural roads are not usually found, such as long stretches of field. According to Kubars and Vachal (2014) study in North Dakota roads, approximately 80 trips are required to provide enough gravel to build access road. The last bit of heavy traffic generated due to the construction of new oil wells is traffic caused by transporting equipment. New York State Department of Environmental Conservation (1998) estimated the equipment truck traffic associate with the construction of a single gas well to be 200 truck trips. Given the low volume of equipment trips and lack of data on the companies providing the equipment, one could easily neglect this factor from the total count of truck traffic.

Table 5 and Table 6 summarize the ESAL values generated with each activity related to a single oil well. From this information, truck traffic appears to be not as critical during the production phase. During construction, which takes roughly 13 days, calculations show that 7699 ESALs can be expected per well. On the other hand, calculations show that a much lower 1945 ESALs can be expected during the production phase, which can last up to a year Therefore, the construction phase occurs in a much shorter period of time and is much more damaging. For this study, truck trip generations for the construction phase with its loadings will be used in the model and linked with routes of travel to predict damages on the pavement.

Table 5: Oil Well Construction Truck Trip Generation.

Construction Activity per Well			
Purpose	**Volume**	**ESAL (Value)**	**ESALs**
Water	1486	2.449	3639.214
Water Disposal	594.4	2.449	1455.6856
Bulk Sand	200	2.449	489.8
Gravel	80	2.449	195.92
Equipment/Other	200	9.59	1918
Total	**2560.4**	**Total**	**7698.6196**

Table 6:Oil Well Production Truck Trip Generation.

Production Activity (Water Disposal)			
Purpose	**Volume**	**ESAL (Value)**	**ESALs**
1st week	476	2.449	1165.724
2nd week	196	2.449	480.004
Up to 60 days	90	2.449	220.41
after 60 days	30	2.449	73.47
Haul Product	2	2.449	4.898
Total	**794**		**1944.506**

3.2.2 GIS Mapping Tool:

The same method used for the Urban Model will be used in this model as well. The Network Analyst closest facility tool helps generate the shortest routes between an incident and a serving facility. In this case, the serving facility will be locations of sand, gravel, fresh water, and water disposal wells. The incidents that need to be served are going to be the wells. Depending on the data, linking ESAL values from the TTGTs with routes generated from the Network Analyst tool will show locations of heavy truck traffic, ultimately indicating where damages are going to occur. Focusing only on the construction traffic which occurs on a two-week period, the model inputs should be updated frequently to capture changes in truck movement patterns. On average, it takes more than 2 months for an oil well to be built after the approval of the oil permit.

For estimation purposes in this model a period of study was determined to be 3 months. The tool is going to be developed using truck trip generation tables linked with route assignment by using origin-destination in ArcGIS's network analyst.

In the following chapter two different models will be discussed based on an Oil and Gas Growth case and an Urban Growth case. The Oil and Gas Model is an example of a model where both the origin and destinations for the trucks are known, and the Urban Growth Model is an example where only origins or only destinations are known. The Oil and Gas Model was built for the Austin TxDOT district area for two periods of analysis, June-August and September-December of 2014. The model will use oil well permits data to forecast routes between oil wells and origins/destinations of facilities servicing the construction of an oil well. The other model will be based in Texas on Williamson County land use permits from July 2014 to July 2015. The model will have two maps, one for production traffic and one for construction truck traffic. Land developments will be connected to the nearest state highway to forecast truck trip routes.

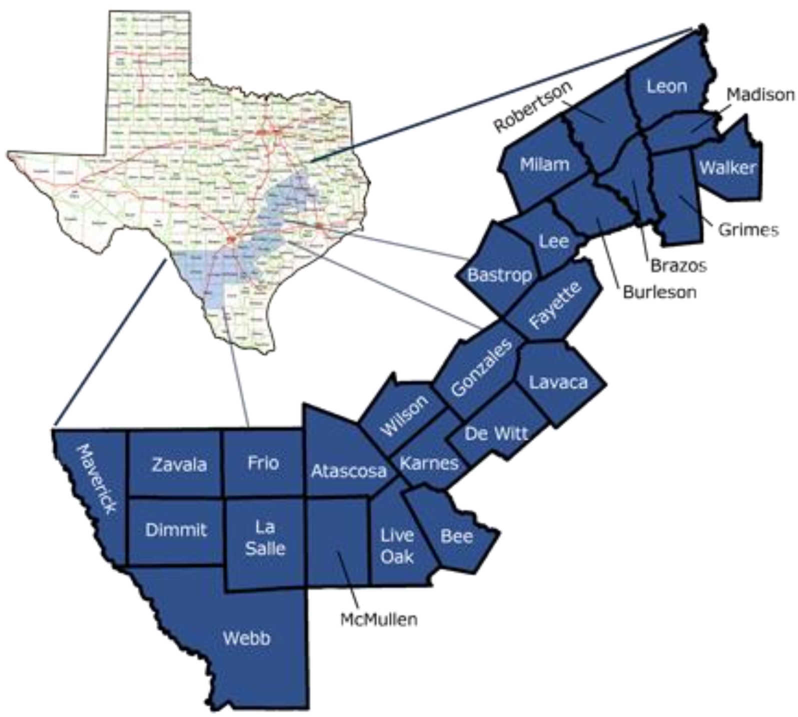
CHAPTER 4: Results from Case Studies

4.1 OIL AND GAS GROWTH MODEL CASE STUDY

4.1.1 Austin District Oil and Gas Growth GIS Model Building:

In this model, we focus on detecting changes in land-use that are specifically related to the oil and gas Industry development in the Austin TxDOT District jurisdictional limits. Figure 6 shows the Texas counties within the Eagle Ford Shale geological area.

Figure 6: Eagle Ford Shale Counties.



Out of those counties, Lee and Bastrop are in Austin TxDOT District area. According to the US Energy Information Administration (USEIA, 2015) list of Top 100 US Oil Fields in terms of production, two fields from the Eagle Ford Shale formation are in the first and fifth ranking. It is also noted that the two fields' production estimate sum is nearly half the production of the top 10 production estimates in total. Moreover, Austin District of TxDOT has 11 counties, 3 out of those 11 had new oil well permits in 2014 according to Railroad Commission of Texas database (TRRC). The Austin District of TxDOT experienced and still experiencing movement of trucks serving oil wells' needs.

4.1.2 GIS Data Sources

The first step in this model to is to determine the data that can be gathered and implemented to follow these truck travel patterns. For this model the list of essential source locations is as follows:

1- Oil wells.

TRRC is responsible for regulating oil and gas permits in Texas. It is the agency that monitors and issues oil well permits so it the right source of data for this model. The RRC online website was used to gather information regarding all the permitted oil wells in the area under the jurisdiction of the Austin District of TxDOT. Oil well names, data, and ownership information is available in Excel format. However, these Excel files now need to have geographic coordinates to know the location of the wells. Along with the well information in excel files are the well API number, where API stands for American Petroleum Institute. The API number is unique for each well in the United States and links it to its X and Y geographic location. The coordinates of those wells must be either purchased or discovered individually by API number using the "Legacy Viewer GIS Tool" on the RRC website. Adding X and Y columns in excel and copying and pasting longitudes and latitudes from RRC website generates tables that are readable by ArcGIS. By studying Caldwell, Bastrop and Lee counties, the model should include all the surrounding counties as well as there will be some oil wells being served by external facilities, or some facilities might service external oil wells. The excel files should include: Caldwell, Bastrop, Lee, Burleson, Fayette, Gonzales, Guadalupe, Milam and Washington counties. In order to capture the 60-day period that on average is the time from approval until construction begins, 2 periods of study for 3 months were chosen for permits approved on June to August, and September to November 2014.

2- <u>Fresh water wells.</u>

Data describing the sources of water supply were obtained from the Texas Commission on Environmental Quality (TCEQ) that takes responsibility for all aspects of planning, permitting, and monitoring. For instance, TCEQ maintains datasets for the water in Texas, and this allows for easy access to shapefiles. Included in the model is the shapefile of “Public Water System Wells & Surface Water Intakes.” This particular shapefile gives the locations of water wells that are most useful to the fracking process.

3- <u>Saltwater disposal wells.</u>

GIS locations for saltwater disposal wells were gathered from the TRRC website the same way as the oil wells. However, disposal wells don’t have approval permit days, only the active disposal wells were taken into account. The data was retrieved on April 1, 2015.

4- Quarries.

Quarry locations supplying sand and gravel were provided by TxDOT Project Advisor Rhonda Roundy, CST. Active quarries were given in the set of data for the Austin TxDOT District Area, and the surrounding districts as well.

5- Roadway network: The roadway network is one of the most important aspects to this project, because it geographically describes the potential paths for trucks to travel. A Shapefile representation of the roadways is used to connect all routes and form a network in the ArcGIS software. The roadway Shapefiles were sourced from Katie Kam, a researcher at the Center of Transportation Research. The file included all the roads in Texas that are maintained by TxDOT in addition to some local roads as well.

6- Texas Counties:

this will serve as the model base map where all the analysis will be based, it will show the geographical political borders between counties. It will also be used to show the study area. The Texas county boundaries map can be found in Texas Natural Resources Information System (TNRIS) website. The file name is All Boundaries found under Maps & Data > Data Catalog > Boundary > Startmap Boundaries.

4.1.3 Austin District Oil and Gas ArcGIS Implementation:

ArcGIS was used to layer the information that had been retrieved. Each location was exported as a Shapefile into ArcGIS providing an extensive model. The majority of the elements in the model require frequent updates. The RRC oil well permit data, for example, is the main layer used in mapping, and this data must be collected for the time period of analysis desired. As stated to build this model, oil well permits for the two time periods: June to August and September to November 2014, were used. The water wells can be updated by using the Shapefiles from TCEQ. Disposal wells should be checked periodically for any updates, but these files are unlikely to change as frequently. In both time periods, the disposal wells had concurrent data. Moreover, quarry information has the least probability for finding available updates since a small number of quarries in the model exist compared to the other data.

The first step is to connect the files that have all the GIS data with ArcMap. In the ArcMap main window, on the right side there is a “Catalog” window that shows the files connected to the software. If “Catalog” window is not visible, one may use the ArcMap main window top bar > Windows > click on Catalog to activate it. Right click on Folder Connection and click on Connect to Folder, navigate to the GIS data folder and click connect. Now add the counties shapefile by dragging the shapefile from the right window into ArcMap main window. The counties map has a specific coordination system that needs to be changed to fit the study area projection system. ArcGIS tools are stored in the ArcToolbox window, for each tool a step-by-step guide will be provided to show how the analysis was done. “Project” tool will be used now and the guided process is as follows:

The tool is found in: ArcToolbox > Data Management Tools > Projections and Transformations > Project.

Input Dataset or Feature Class: StratMap_County_Poly

Output Dataset or Feature Class: Counties

Output Coordinate System: NAD_1983_StatePlane_Texas_Central_FIPS_4203_Feet

RUN

The output has the counties projected to the Central Texas projection system. Now manually selecting the counties in the Austin District of TxDOT would be ideal to differentiate between the study area and the surrounding counties. This can be done by clicking on the “Select Feature” button then holding the “Shift” key on the keyboard and manually selecting each county. The selected counties then can be exported to a new layer by right clicking on the Counties shapefile > Selection > Create Layer from Selected Features and now the based map for the model is ready. The next step is to import the oil shapefiles. Oil well data for the two time periods are in Excel format. Exporting XY coordinates can be done by changing the excel file format to “Microsoft excel 97-2003 worksheet (xls)” for ArcGIS to be able to read the tables. The “Make XY Event Layer” is a tool that would be used to create a point layer from XY data tables. Following is a guide to use the tool “Make XY Event Layer”

The tool is found in: ArcToolbox > Data Management Tools > Layers and Table View > Make XY Event Layer.

XY Table: OilWells (For oil wells in the 1^{st} period (June-August 2014) OilWells2 is the 2^{nd} period)

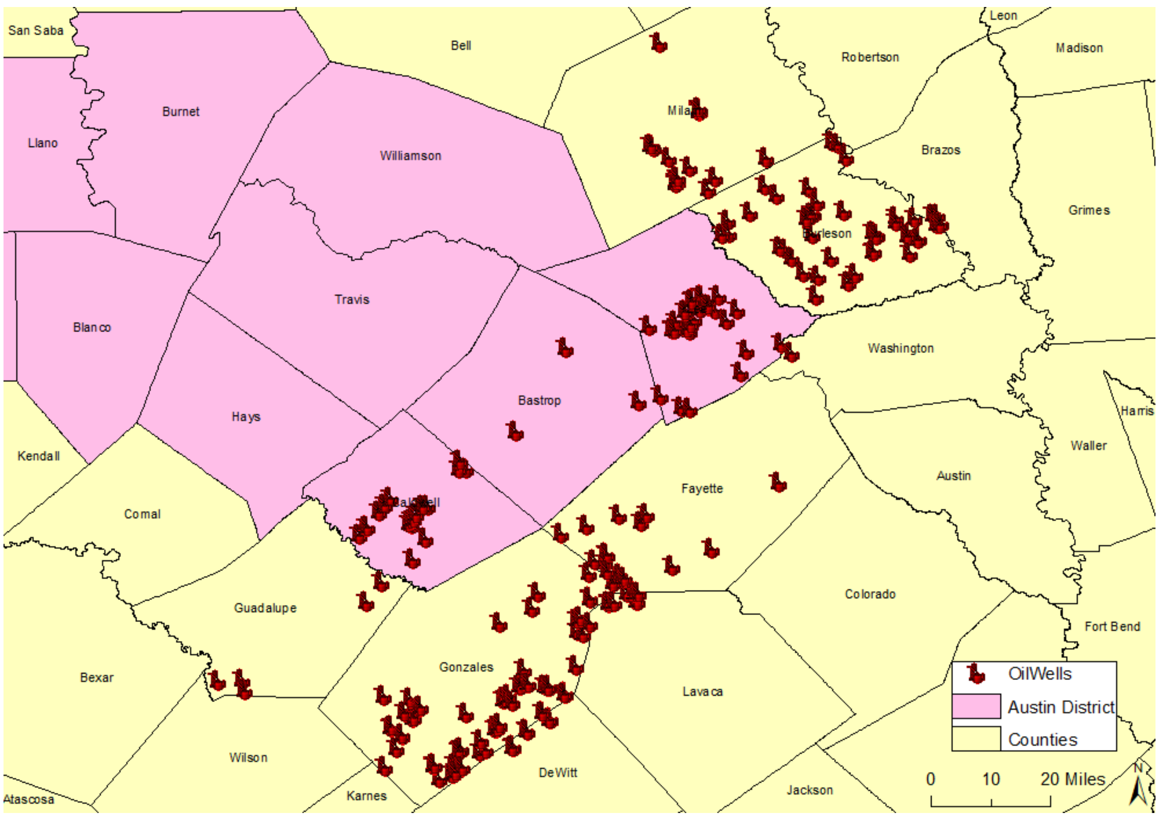
X Field: X (The column name that was created in the excel files for Longitude)

Y Field: Y (Latitude)

Layer Name or Table View: OilWells (Name of shapefile output)

Spatial Reference: NAD_1983_StatePlane_Texas_Central_FIPS_4203_Feet (this is used because it contains most of counties in the study area: Bastrop and Lee. However, Caldwell is on South Central 4204); RUN; Output:

Figure 7: Oil Wells (Period 1).



The output in figure 7 shows locations for oil wells converted from Excel files into ArcGIS shapefile and projected to the “NAD 1983 StatePlane Texas Central FIPS 4203 Feet”. The same method works for oil wells 2 (the second three month time period) and disposal wells. Quarry locations and fresh water wells are shapefiles, shapfiles are readable by ArcGIS but these shapfiles need to be projected so that their coordination system matches the model coordinate system. The "Project" tool that was used to project the counties shapefile can be used for the projection of quarries and fresh water wells as well. The model now should have oil wells, oil well 2, disposal wells, quarries and fresh water wells.

The next step after importing source information data into ArcGIS is creating a road network. Having a road network, one can implement network analyst's closest facility tool to find the route assignment. The first step is to activate the network analyst extension: ArcMap main window top bar > Customize > Extensions… > click on Network Analyst to activate it. Adding Network analyst toolbar as follows: ArcMap main window top bar > Customize > Toolbars > click on Network Analyst to add it. Following is a guide on how to create/build a network dataset:

Navigating to the network shapefile in Catalog and right clicking on it, clicking on "New Network Dataset…" will open a window to help build a network dataset. Following is a guide for each window:

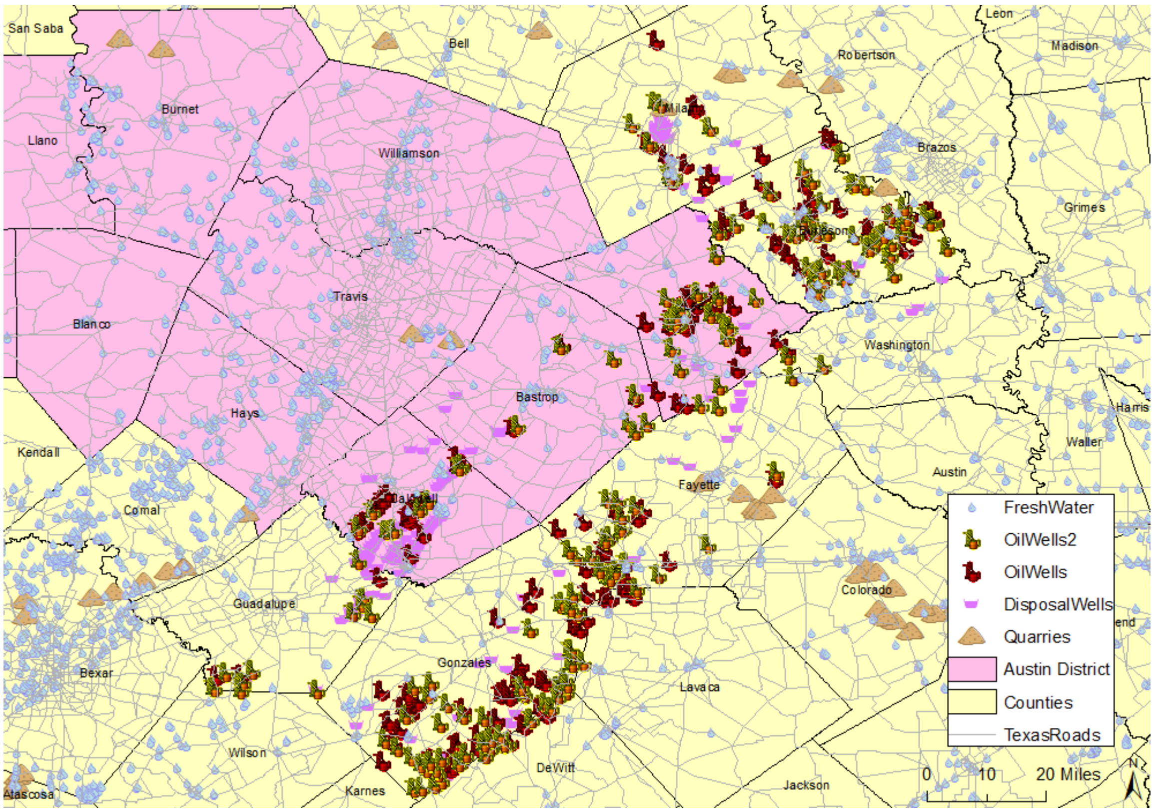
1- Enter a name for your network dataset: TexasRoads
2- Do you want to model turns in this network? YES
3- Check that connectivity policy is end points
4- How would you like to model the elevation of your network features? NONE
5- Make sure that the units are: Miles
6- Next

7- Do you want to establish driving direction settings for this network dataset? Depending on the user output needs, for this model we chose YES.

8- Finish

The output will have two parts, the edges which are the street lines and junctions which represent all the junctions in the network. In this model only the street lines will be needed. Figure 8 shows the inputs of all the data in this model.

Figure 8: All Model inputs.



Oil wells, disposal wells and quarries are locations in the study area parameters. However, TCEQ freshwater locations are in the State of Texas. This will generate a problem when trying to find the closest water well to an oil well. The TCEQ file contains 17206 water wells, clipping the data to our area parameter is needed for the software to calculate routes efficiently and only include inputs that are considered important. Manually selecting these counties: Caldwell, Bastrop, Lee, Burleson, Fayette, Gonzales, Guadalupe, Milam, Washington, Travis, Williamson and Hays will cover the surrounding area. Exporting these selected features as a layer will generate a layer that we want to use in the next step. "Clip" is a tool that is used to trim the shapefile based on the boundaries of another. In other words, the FreshWater shapefile will be clipped based on the surrounding counties shapefile. The output will only have FreshWater wells that are in the surrounding counties boundaries. A guided illustration is as follows:

The tool is found in: ArcToolbox > Analysis Tools > Extract > Clip

Input Features: FreshWater

Clip Features: SurroundingCounties

Output Coordinate Class: FreshWater1; RUN

Table7 shows a breakdown of the steps needed to set up the model.

Table 7: ArcGIS Tools For Creating The Model.

Tool location	Tool	Inputs	Output	Notes
DMT>Projections and Transformations>	Project	Startmap_County_Poly	Counties	
DMT>Layers and Table View>	Make XY Event Layer	Inputs: Oilwells, (OilWells2 2nd run)	All_Routes_EndPoints	Spattial Reference: NAD_1983_StatePlane_Texas_Central_FIPS_4203_Feet
ArcCatalog	Build a new tool (Right click on Roads Shapefile)	TxDOT Roads	TexasRoads	Model U Turns: Yes Units: Miles
Analysis Tools>Extract	Clip	TCEQ_PWS	FreshWater	Clip Feature: SurroundingCounties

The next step is to find the shortest path between the origins and destinations. Many points can be selected as incidents or facilities. The definition of incidents in ArcGIS is the location that needs to be served. For this case, the oil wells are incidents or important factors on which to focus more attention. Facilities, on the other hand, serve the incidents so quarries, disposal wells and water wells will be the facilities. Running the tool will generate the route assignments that are later going to have specific ESAL values added to identify locations of heavy loadings compared to other locations. A guide on how to use Closest facility function for quarries linked with oil wells for the 1st period is explained below:

On the Network Analyst toolbar click on the Network Analyst dropdown menu and choose new Closest Facility. Click on the Network Analyst Window button to activate the tool window that will be located on the left side of the main ArcMap window. Right click on Facilities > Load locations… > Load from: Quarries (Make sure location position is set based on "Use Geometry" 10 Miles, to connect the facility to the nearest network lines within a 10-mile radius) Click OK to load facilities. The same method can be followed to load OilWells into incidents. Now the facilities and incidents locations are loaded, click on the solve button in the Network Analyst toolbar to find the shortest paths. Figure 9 shows the output of the network analyst tool with the shortest routes between quarries and oil wells (1st period).

Figure 9: Network Analyst: Closest Facility Output: Quarry to Oil Wells.

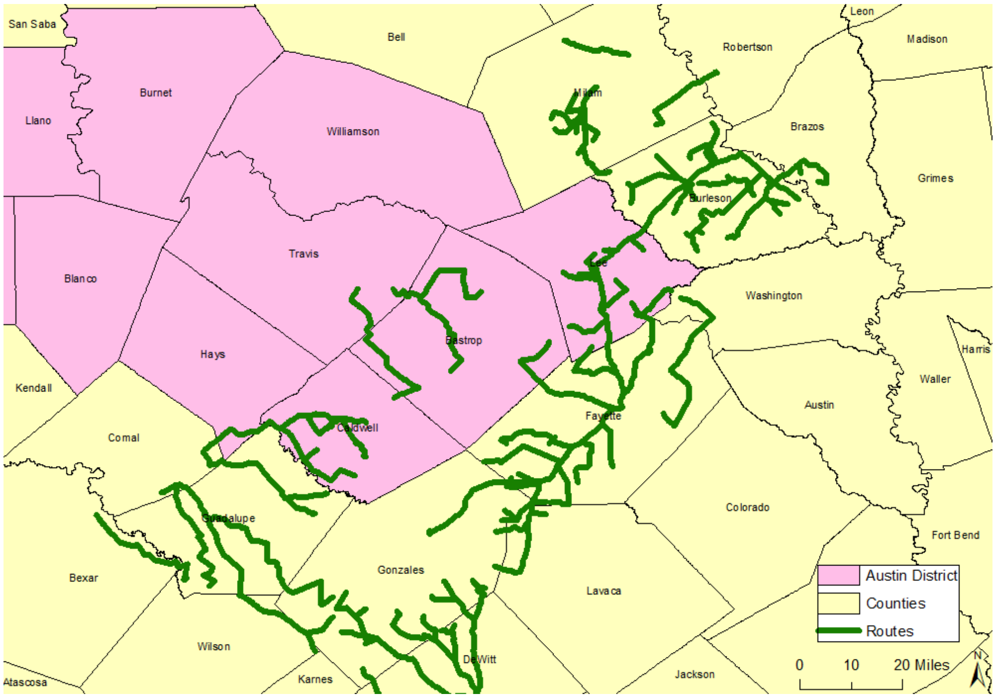


Figure 9 shows the shortest paths between OilWells1 and Quarries. The routes are connecting each oil well to the nearest quarry. Moreover, running the tool for each route will generate 6 routes: Quarry to OilWells (QO), Quarry to OilWells2 (QO2), Disposal to OilWells (DO), Disposal to OilWells2 (DO2), Water wells to OilWells (WO) and Water wells to OilWells2 (WO2). These 6 routes have different ESAL values associated with each route. Adding an ESAL value field in each routes attribute table is crucial in this step for further analysis. The guide below shows how to add ESAL values for each route.

The first step is to right click on Routes in each closest facility output drop down menu > Data > Export Data… > and name each route accordingly. Example, Quarry to OilWells will be named “QO”. Right click on QO > Open attribute table > Table Options >

Add field… > Name: ESAL , Type: Double (Double is used for numerical values) then OK. To add values for the field, right click on ESAL field > Field Calculator > then type 686 in the “ESAL=” open box. The value 686 is the ESAL value associated with quarry trips in QO and QO2, 1456 will be used with DO and DO2, 3640 will be used in WO and WO2.

Analysis Method 1:

To classify routes in order of their importance, or to know where the highest ESAL loading will occur, certain tools in ArcGIS can be used. One of those tools will arrange routes in order of the ESAL loading and represent them with a proportional width of line. For example, Water well to Oil wells (WO) has the highest ESAL loading of 3,640 per route. Line size of 8 will be used for the WO routes. The second highest ESAL loading is Disposal wells to Oil Wells (DO) that have an ESAL loading of 1,456 per route. Line size 6 will be used for this route. Leaving Quarry to Oil wells (QO) with a line size of 4 for their 686 ESAL loadings. Figure 10 shows the breakdown of routes and their line sizes. Different colors will be assigned for each route to make it easier to visually differentiate. Routes from the second study period will have 1 size smaller lines. This means WO2 will have size 7, DO2 will have size 5 and QO2 will have size 3. Figure 10 shows what the model would look like with different widths and colors.

Figure 10: All Shortest Path Routes Between Incidents and Facilities.

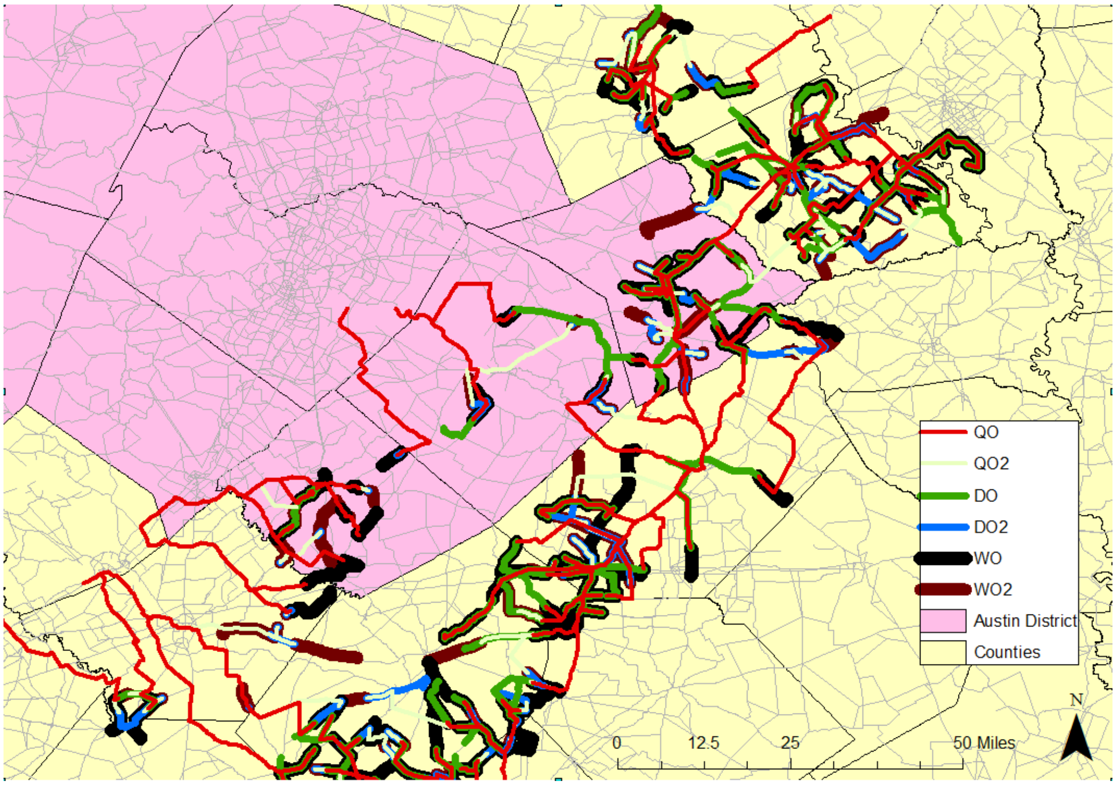


Figure 10 shows all the shortest routes from incidents and facilities in the model. each trip purpose in each study period has a specific width and color. It is really hard to say which areas are of concern from the first look at the model. However, further analysis should be done to help get to that point. The first step is to eliminate routes that are not going to be important. A tool in ArcGIS lets the user eliminate routes with one trip only. The “Intersect” tool will generate an output that contains intersected trip routes. This means if there is only one trip in a specific route, that does not intersect with any other trip route, this trip will be eliminated. Running the tool will help in the process of eliminating areas that are not of concern.

Example of running the intersect tool for one of the routes is illustrated below.

The tool is found in: ArcToolbox > Analysis Tools > Overlay > Intersect

Input features: QO

Output: Quarry; RUN; Output:

Figure 11: Quarry Routes with 2 or more trips involved.

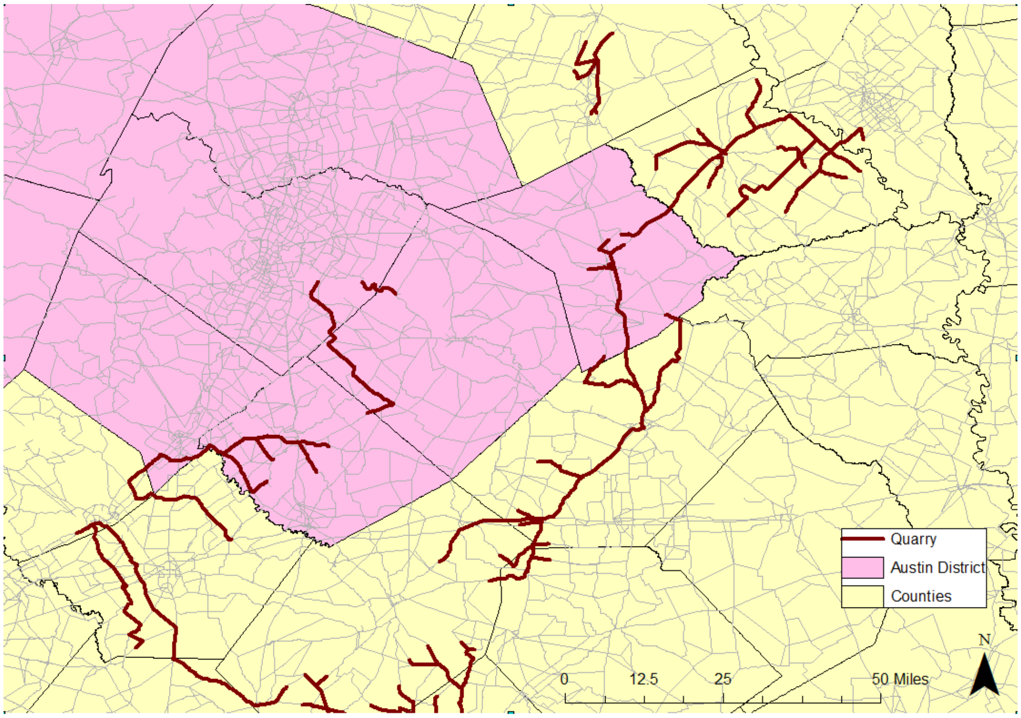
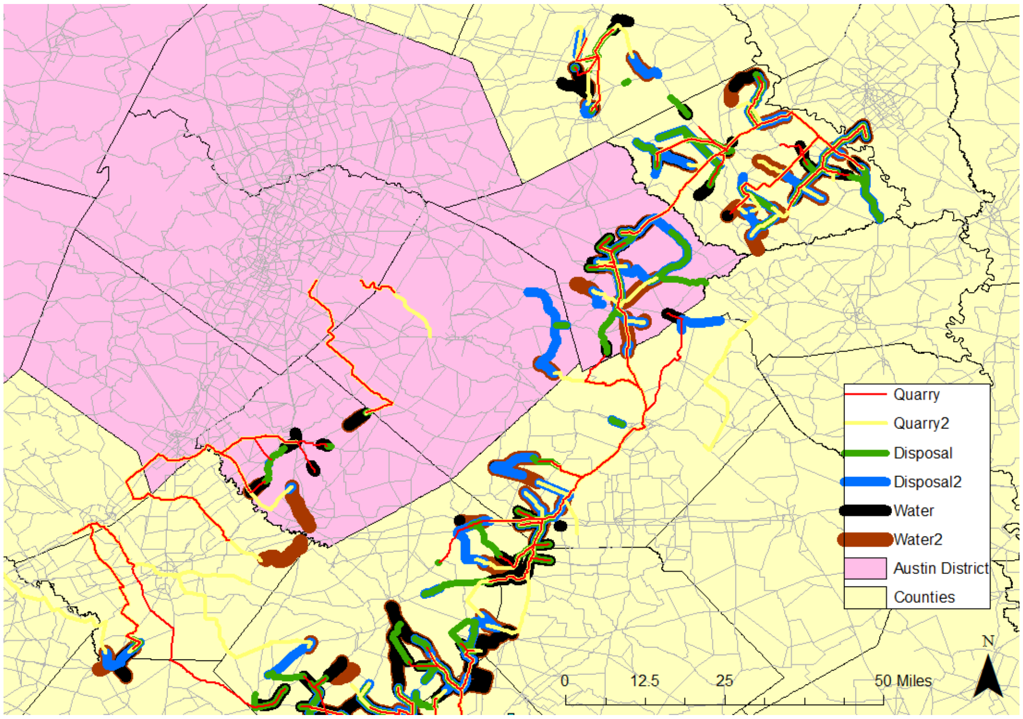


Figure 11 shows the output of running the Intersect tool on QO routes. Running the other 5 routes on the same tool is needed now to eliminate all other non-important truck effects. Figure 12 shows the final output before manually analyzing each county in the Austin district. The model now contains only routes with 2 or more trips in each route.

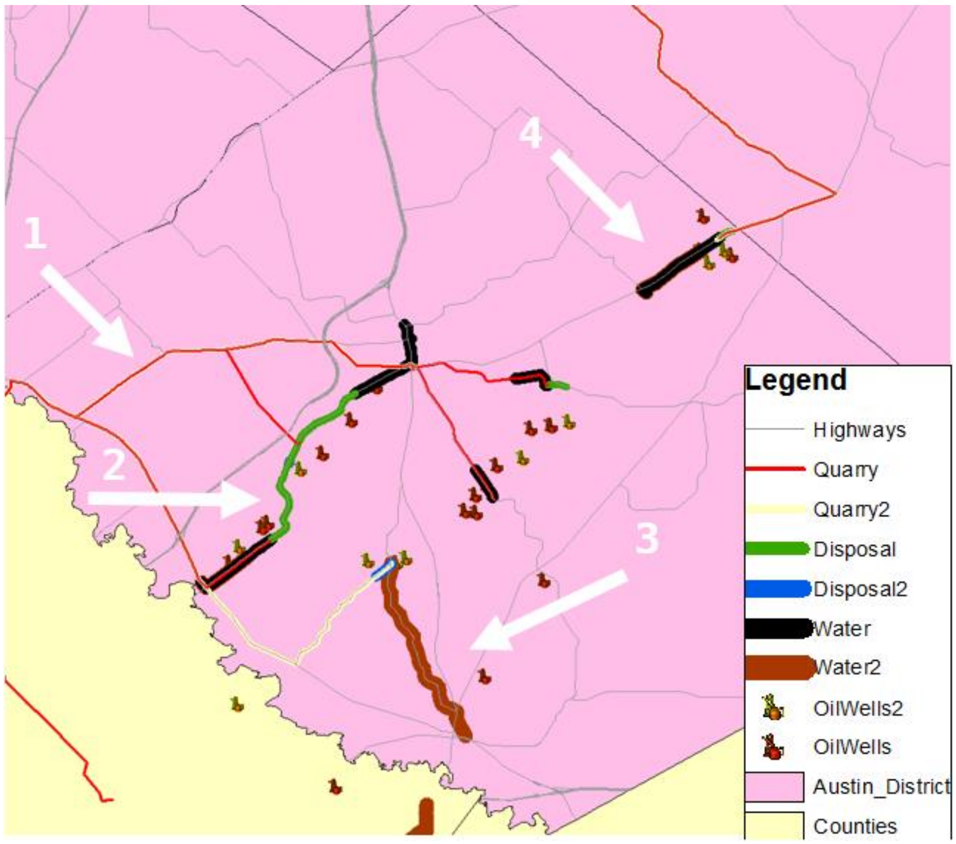
Figure 12: All routes with two or more trips overlapping in the same route.



Comparing Figure 12 to Figure 10 shows a significant reduction in the number of routes. This reduction is much needed at this point before analyzing each route since it saves time for users of the model. Further visual inspection of each county is needed to determine which routes seem important enough to calculate their ESAL values. The first step is to divide the analysis area by county and then follow simple steps to eliminate or examine routes. Rules of thumb for this analysis might include the facts that WO routes carry 3640 ESALs which is more important than 5 routes of QO, given that QO carry 686 ESALs, and 2 routes of DO that experience 1456 ESALs. Since we already eliminated routes with one WO trip and we only included 2 or more WO trip routes, then any routes with 10 QO trips or 4 DO are automatically not important as well. Starting from

Caldwell county, by zooming in it is obvious that there are 4 areas of concern in this county as shown in Figure 13.

Figure 13: Caldwell county critical segments.



Each route should be investigated individually by zooming in on the route and selecting each route, opening the attribute tables for each route type, and manually calculating ESAL loading in the segment by multiplying the ESAL number by how many trips are using the segment. Selecting a segment and opening the attribute table for its route, a number of selected features will appear in the lower part of the tables. Another identification of the number of the selected feature, is in the lower left corner of the general software window. After selecting a segment in the model a small line will pop up in the lower left corner showing the number of selected features.

Figure 14: Caldwell segment #1

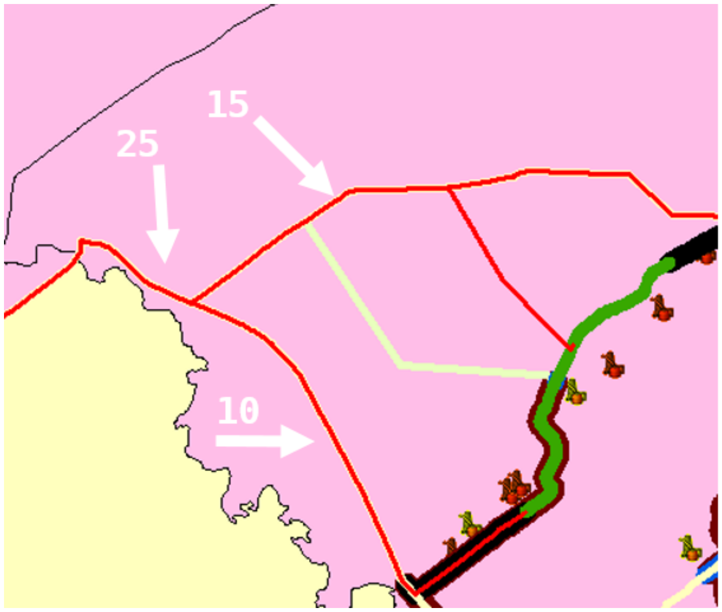
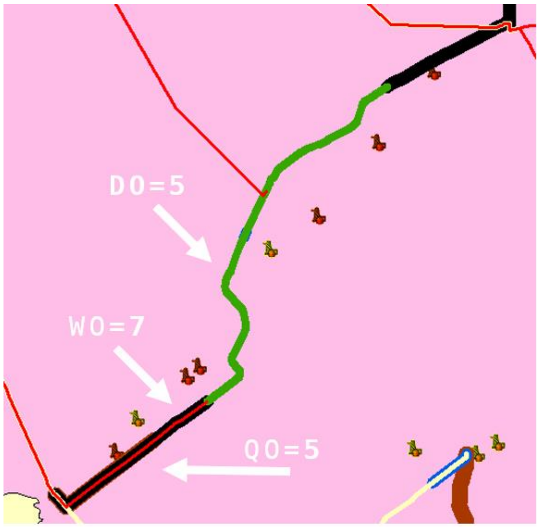


Figure 14 shows segment #1 in Caldwell county which includes 3 routes that might be of concern. These routes are only QO routes meaning that the only ESAL values associated with these routes is 686. The part containing 10 QO routes will automatically be out of concern since its less than the 2 WO routes. The remaining routes will have values of 15x686=10290 ESALs and 25x686=17150 ESALs.

Some routes will have a combination of OQ, OD and OW overlapping. In these areas the user should activate each route class by itself and then identify how many trips in this segment are associated with this route class. Caldwell segment #2 shows the 3 route classes overlapping which makes it hard to identify how many trips are in each route unless it was studied by class and then adding the total ESAL value for the whole segment. Figure 15 shows Caldwell segment #2 and how many trips of each route.

Figure 15: Caldwell segment #2



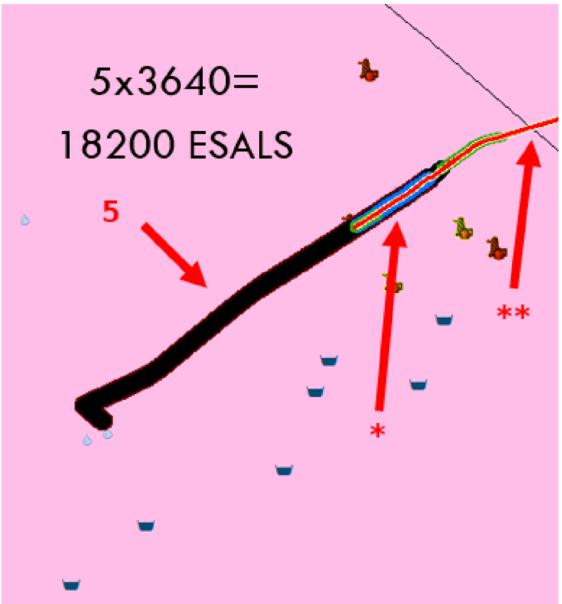
Multiplying numbers of trips for each route by its ESAL value and adding all ESAL values will give the user to total ESAL value generated in this segment. This segment ESAL value is: 5x686= 3430 + 5x1456=7280 + 7x3640=25480, Total= 36190 ESALs.

Figure 16: Caldwell segment #3

Figure 16 shows Caldwell segment #3 that has 3 OW2 paths, 3x3640=10920 ESALs. In Figure 17 Caldwell segment #4 has 5 OW&OW2 paths or 5x3640=18200 ESALs.

In section *, on the higher right corner of the figure, the quarry route holds 5 routes only which is less important than one water route and section **, the route containing the disposal is insignificant because of its small size.

Figure 17: Bastrop critical segment



It is obvious that Lee County would have the highest truck traffic in this model. It was predictable based on the oil well counts, given that Lee has 72 oil wells compared to 8 in Bastrop and 28 in Caldwell. Bastrop county was studied and the worst case scenario route had an ESAL value of 18,200. In Lee County, there are more than 3 areas of concern but going through each area, Figure 18 shows the highest ESALs value for the 3 areas of concern. Figure 19, Figure 20 and Figure 21 shows the ESALs values for each area.

Figure 18: Lee critical segments

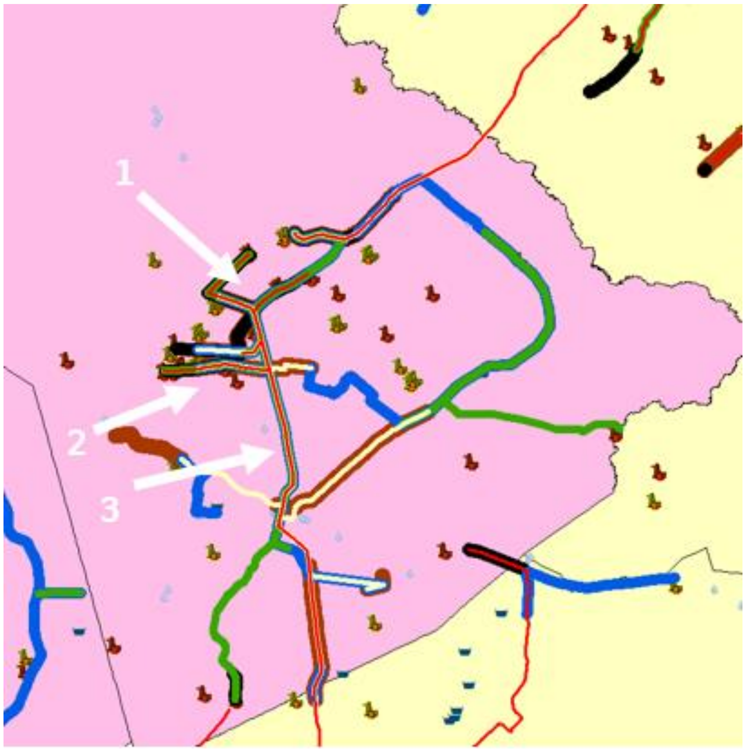
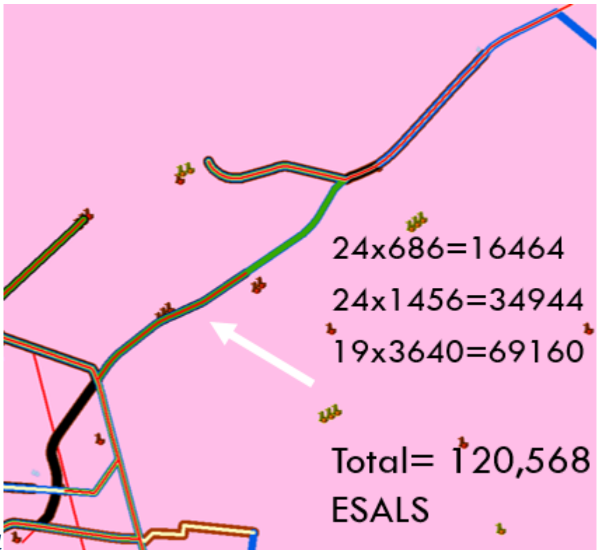


Figure 19: Lee segment #



1

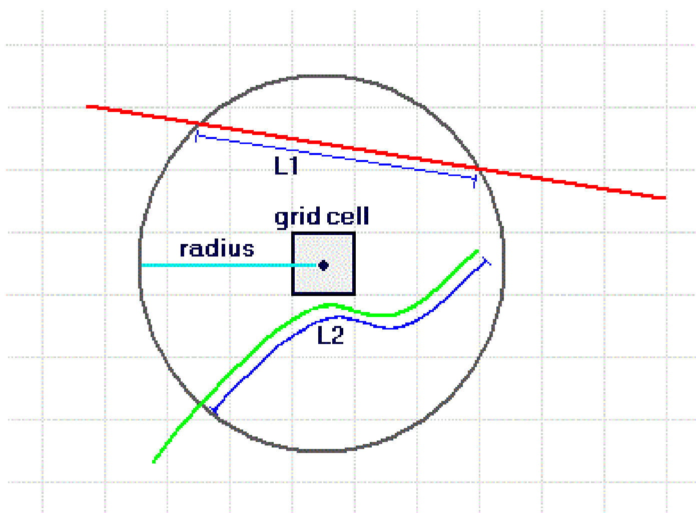
Figure 20: Lee segment #2

Figure 21: Lee segment #3

Analysis Method 2:

Another way to classify areas of concern is through spatial analysis extension. The extension, just like the Network Analyst needs to be activated before the analysis is made. First step is to find the line density in each of the 6 routes. According to ArcGIS resource center, line density tool calculates polyline feature density by multiplying the line length by the “Population field” and dividing it by the area of grid cells. Usually the grid cells areas are set by default for lines generated by the network analyst outputs. So the variables here are “Population field” and length of line. Figure 21 shows how the tool works.

Figure 22: Density Line Tool. Source: ArcGIS Resource Center 2011.



Density = ((L1 * V1) + (L2 * V2)) / (area_of_circle)

ESALs will be the variable that will be used as the “Population field” to generate how many repetitive ESALs are applied to each segment in comparison to the rest of the route segments. Length of the line will be calculated spatially by the tool. An example of running the Density tool for one of the routes is illustrated below.

The tool is found in: ArcToolbox > Spatial Analyst Tools > Density > Line Density

Input Polyline features: QO (Quarry to Oil well)

Population field: ESAL; RUN; Output:

Figure 23: Quarry to Oil routes: ESAL Density

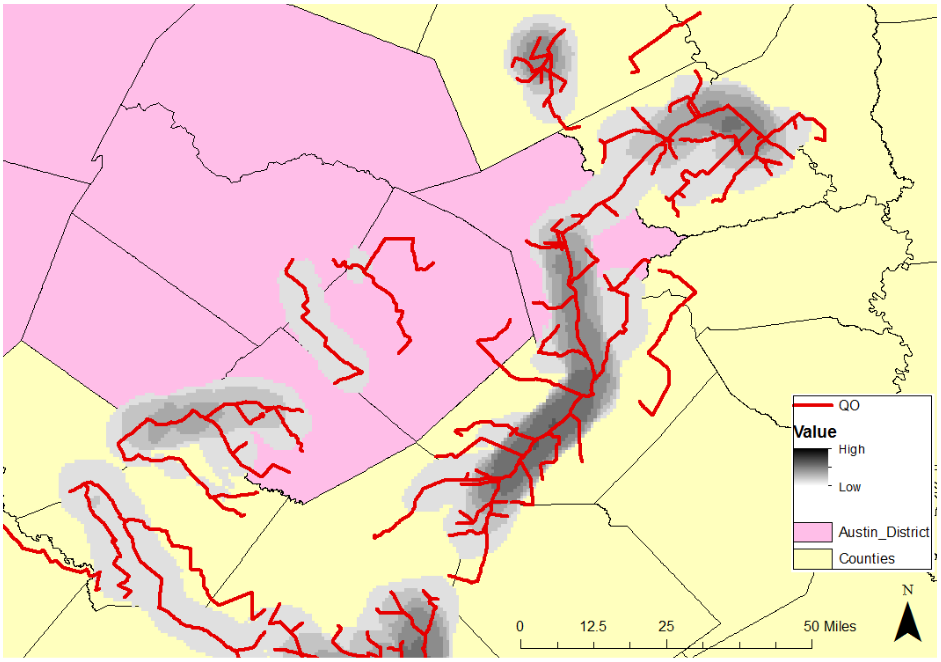


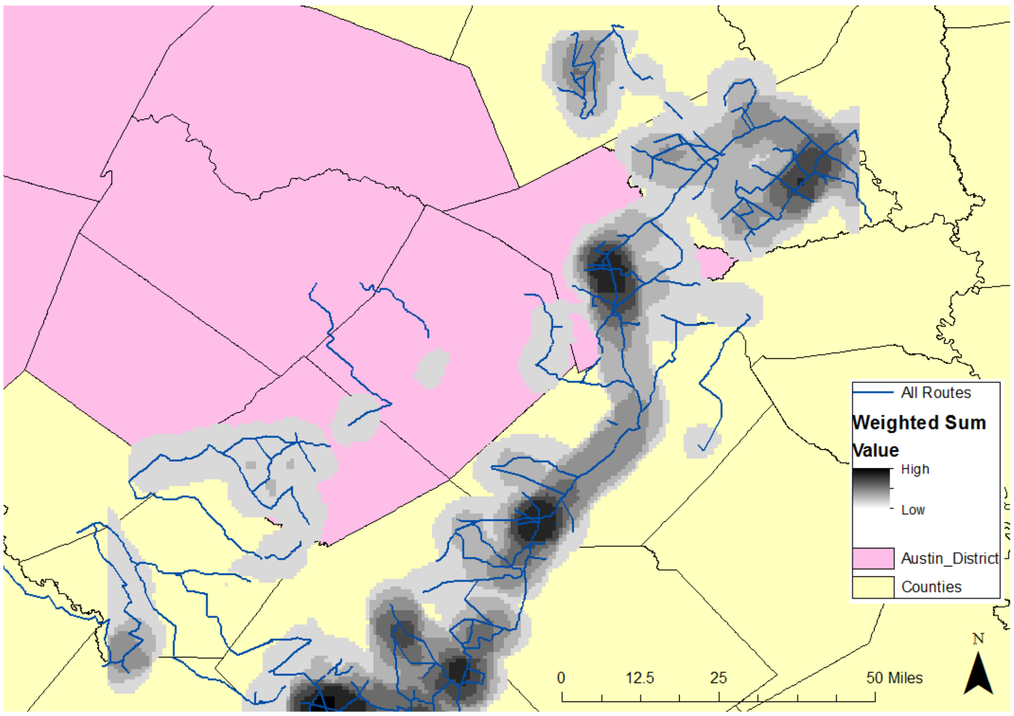
Figure 23 shows the variation of the density of ESAL values associated with Quarry to Oil routes. The output shows the ESAL density values as black when it is high, white when it is low. Running the density line tool for the remaining 5 routes will generate 5 outputs. At this point we have 6 different areas of concern for each route. The next step is to join these 6 outputs into 1 output that shows the general areas of concern taking into account all the inputs from the origins to destinations and how heavy the truck traffic travelling in these routes will be and finally shows where there should be concern.

The weighted sum tool can help join the 6 density line routes generated in the previous step. According to ArcGIS Resource Center (2011), the tool combines multiple raster inputs, representing multiple variables to one raster output. The output will show the weighted sum of all the inputs, this means that the output will show the sum of inputs depending on their ESAL values importance from high to low. This tool is ideal in our study since we are concerned with more ESAL loaded routes.

The tool is found in: ArcToolbox > Spatial Analyst Tools > Overlay > Weighted Sum

Input Polyline features: QO, QO2, DO, DO2, WO, WO2; RUN; Output:

Figure 24: All Routes ESAL Density



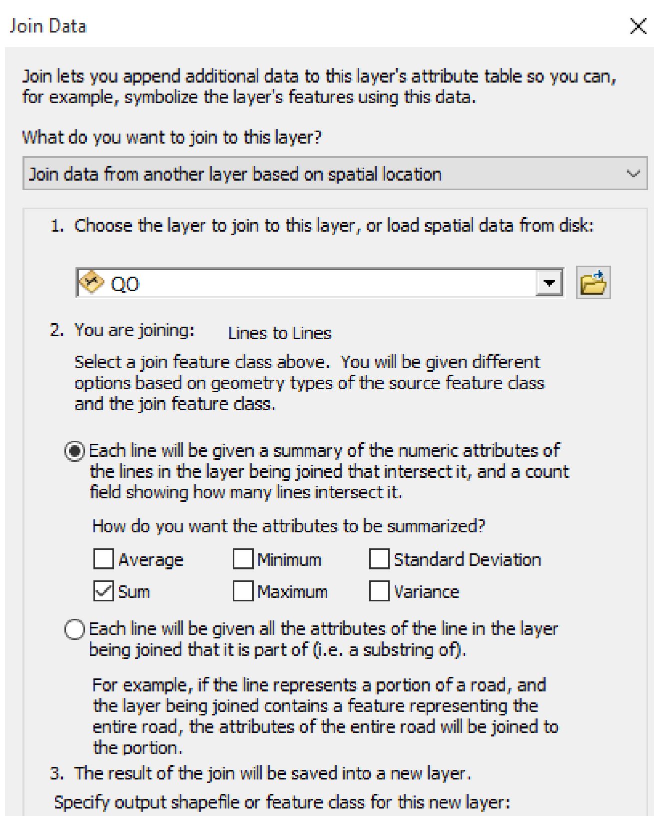
All routes now are accounted for in the model, in Figure 24 the user can tell that there's a high density of ESAL values in Lee county. The final output helps the engineer to locate where attention is needed, by following this output the highest area of concern is located in Lee county. Exactly like what the method of "Widths and Colors" predicted. However, these two methods can work greatly depending on the choice of the user. In this thesis there was a process of building an accurate tool, so visually inspecting each county by different widths and colors generated areas of interest based on exact ESALs. The spatial analysis method is very helpful for engineers who are concerned about time spent on the model and wanting a general area of concern in a specific county. The user can go back and forth with both tools to double check results.

Analysis Method 3:

There is a third technique to follow to know the location of where the most damages are going to occur. This technique can be tricky and the process is longer than the previous two but the upside of it is that it breaks down the importance of segments based on ESAL values. The first step is to merge all the routes, QO, QO2, DO, DO2, WO, WO2 into one single route and name it “All_Routes”. The “Merge” tool can be found in the geoprocessing drop down menu. After merging the routes, the user should create points where the lines end. This will help to know where routes start and end, on the merged network of routes. Naming this output “All_Routes_EndPoints” will be ideal since the model will require more shapefiles to be created, so naming at each step will help to differentiate the inputs and outputs. Back to the “All_Routes” merged file, we use the “dissolve” tool to dissolve all the routes and come up with one route that we are going to use as the base map for further analysis. The output file should be named, “All_Routes_Diss”. The base map of routes needs to be divided every time there is a different route experience, or in another words it needs to be divided based on where intersections of travel activities are happening. The “All_Routes_EndPoints” shapefile contains these intersections of travel activities, as it tells the end or start of each trip. A tool that splits line based on points is called “Split line at point”. “All_Routes_Diss” and “All_Routes_EndPoints” are the inputs for the tool “split line at point” that will generate a new shapefile, “All_Routes_Split”, that have spatial segments of where the routes are intersecting and also contains the single trip routes. This tool is important because it will let the software know that there might be a chance of trips occurring on this route and it does have a value, furthermore these split routes will be used to calculate how many trips are using each segment and what are the ESAL values associated with each. The next step is to spatially join “Total ESALs” to each route, QO, QO2, DO, DO2, WO, WO2, and add a field to sum the ESAL value experience in each segment.

The first step is to right click on “All_Routes_Split” > Join and Relates > Join… Figure 25 shows the window and what options to choose to successfully spatially join the routes.

Figure 25: Join Data window inputs



The output file would be named automatically “Join_Output” no need to rename it since this is not the final output and, the next step is to Spatially join “Join_Output” with QO2, this will give an output of “Join_Output2”. Following the same method will lead to a “Join_Output6” this file is the final output as it holds all the ESALs values. The last step is to add a field in the attribute table and name it “Total_ESAL”. Using the field calculator tool in the attribute table, this equation must be used to sum all the ESALs in each segment. Total_ESAL= [Sum_ESAL]+ [Sum_ESAL_1]+ [Sum_ESAL_2]+ [Sum_ESAL_3]+ [Sum_ESAL_4]+ [Sum_ESAL_5]. The Total_ESAL field now has ESAL values of all the unexpected traffic that will most likely travel in this 6 month sudy period. The user of the software can generate a visual output depending on the ESAL value. Figure 26 shows different levels of ESALs using a 50,000 ESAL interval. Figure 27 shows only routes in the Austin District area that are going to experience ESALs of more than 20,000. Table 8 shows the steps to produce the output.

Figure 26: Final output showing exact ESAL numbers on each route

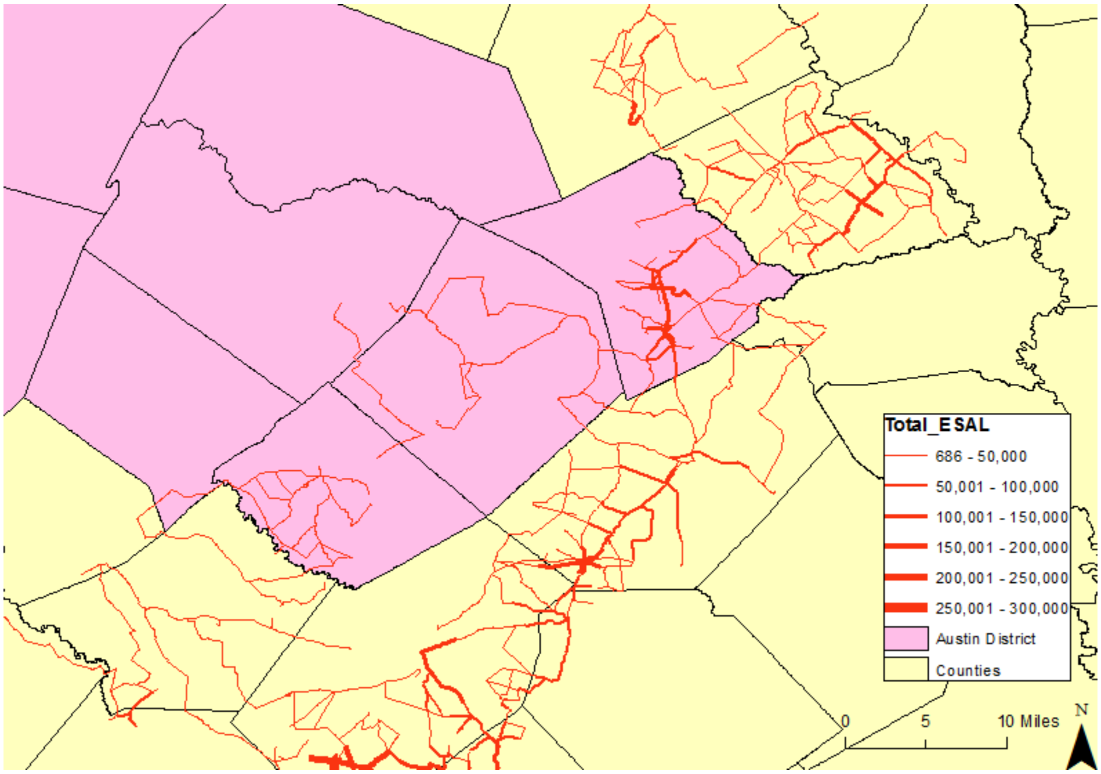


Figure 27: Caldwell, Bastrop and Lee counties additional unexpected ESAL values.

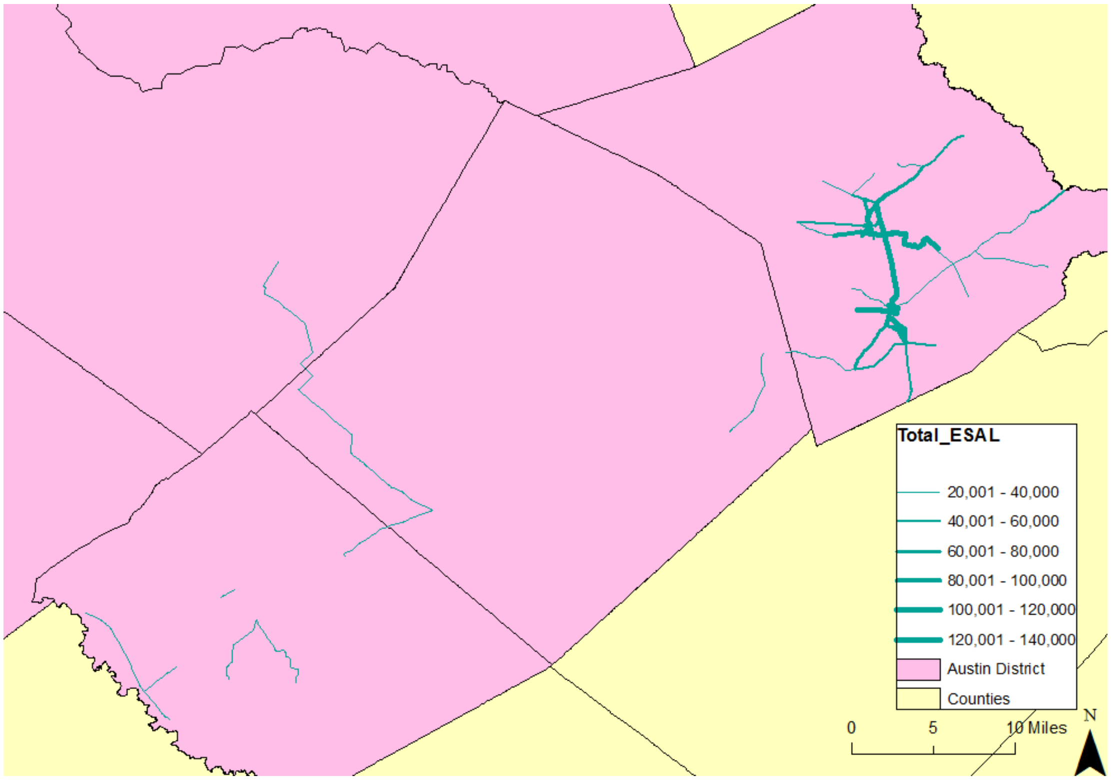


Table 8: ArcGIS analysis method#3 step-by-step tool guide.

Steps	Tool location	Tool	Inputs	Output
1	DMT>General>	Merge	QO,QO2,DO,DO2,WO,WO2	All_Routes
2	DMT>Features>	Feature Vertices To Points	All_Routes	All_Routes_EndPoints
3	DMT>Generalization>	Dissolve	All_Routes	All_Routes_Diss
4	DMT>Features>	Split Line At Point	Feature:All_Routes_Diss Point:All_Routes_EndPoints	All_Routes_Split
5	Join and Relates	Join>All_Routes_Split	QO	Join_Output
6	Join and Relates	Join>Join_Output	QO2	Join_Output1
7	Join and Relates	Join>Join_Output1	DO	Join_Output2
8	Join and Relates	Join>Join_Output2	DO2	Join_Output3
9	Join and Relates	Join>Join_Output3	WO	Join_Output4
10	Join and Relates	Join>Join_Output4	WO2	Total_ESAL
*DMT=Data Management Tools				

4.2 URBAN GROWTH MODEL CASE STUDY

4.2.1 Williamson County Urban Growth Model Building:

Texas is the 2nd highest state in terms of VMT in the US with total truck VMT with more than 2 hundred billion VMT (USDOT, 2014). The ongoing truck traffic growth in Texas is directly related to land use changes. In 2014, Williamson County was ranked one of the three fastest growing counties in the nation by the US Census (US Census, 2015). Williamson county is located in Central Texas on the I35 corridor, this makes the county prone to Industrial interest since most industrial plants are located to simplify logistics. More people moving to the County generate more business interest. Officials in such a small county usually are not prepared for sudden growth, especially in their counties' infrastructure needs. In this model, Williamson County was chosen because of the ongoing urban growth as this county represents the best location where the model can be implemented. This model will generate ESAL based truck trip generation and try to predict truck travel patterns, producing a model that can follow urban growth impacts.

The base of this model is Williamson county building permits GIS data that shows the location of future developments. These data will be used to develop a truck flow impact model. The data is compiled of locations of future developments that are approved by the county. It will be divided into three categories: residential, commercial and industrial. Truck flow will be directly dependent on the size of the development generating different levels of importance, bigger development will generally attract more truck traffic in comparison to other developments in the same category.

Certain assumptions are made since it is really almost impractical to find origins and destinations of all truck trips in this model. Trucks are assumed to have the maximum legal weight of 80Kips, although this is overestimating and heavy since some trucks have the trailer filled out volume wise. Following the production tables formed in the methodology section, construction rates will be the same. However, production tables will be converted to fit an annual estimation, making the model valid for one year and can be updateable based on source data updates. Assuming industrial, manufacturing and warehouse land uses only work 5 days a week, an average of 250 days per year is when they are sending/receiving trucks. Grocery stores and residential land uses are going to be active 365 days a year. Tables 9 and 10 show the rates that are going to be used in the production and construction models.

Table 9: Construction Truck Trip Generation

Construction Activity Rates				
Purpose	**Volume**		**ESAL (Value)**	**ESALs/Trip**
All Purposes	1	/1000 SF	2.449	2.449
Residential	2	/House	2.449	4.898
*Average house lot size is 18,000SF, Use 15,000SF				

Table 10: Production Truck Trip Generation

Production ESALs Rates					
Purpose	**Volume**		**Time (Days)**	**ESAL (Value)**	**ESALs/Trip/year**
Industrial	0.38	/1000 SF	250	2.449	232.655
Grocery store	0.51	/1000 SF	365	2.449	455.88135
Manufacturing	0.35	/1000 SF	250	2.449	214.2875
Warehouse	0.44	/1000 SF	250	2.449	269.39
Residential	0.011	/1000 SF	365	2.449	9.832735

4.2.2 GIS Data Sources:

1- Roadway network and Texas Counties: The same sources as the Oil and Gas model was used. (the roadway Shapefile provided by Katie Kam, a researcher at the Center of Transportation Research) and the Texas counties boundaries shapefile from Texas Natural Resources Information System (TNRIS) database.

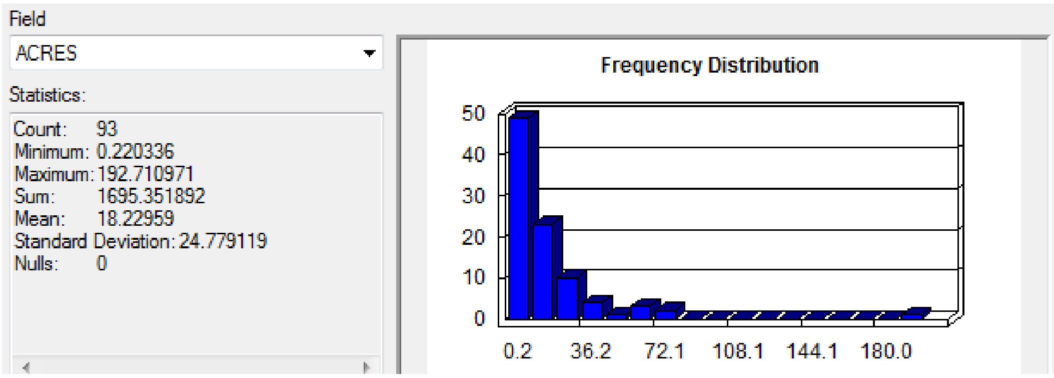
2- Williamson county new developments: This shapefile was obtained from Patrick Hughes, a civil engineer at Williamson County who is responsible for GIS and mapping. This file is the base of this model, as every GIS based models, data is the cornerstone of the study. The shapefile contains 493 inputs:

A- 242 inputs with no "Approval Date"

B- 158 inputs with approval dates from 1998 to June 2014

C- 93 inputs with approval dates from July 2014 to July 2015 (this is the data that is going to be used in this model) Table 28 shows statistics of the data in terms of Acres and the frequency distribution of the 93 inputs.

Figure 28: Williamson one year data sample acre statistics



4.2.3 Williamson County Urban Growth ArcGIS Implementation:

Model creation is begun in ArcMap by adding TexasRoads, counties and Williamson county shapefiles. Projecting all files to "NAD 1983 StatePlane Texas Central FIPS 4203 Feet" must be done before any analysis is made. Exporting Williamson county from counties can be done by selecting it manually from counties and creating a layer for the selection. A new shapefile containing the data related to the study period must be created. Right click on the Williamson county new developments shapefile > open attribute table > choose the data contained in the study period based on the approval date > right click again on the Williamson county new developments shapefile > Data > Export Data... and save the data as July14-July15. The data contains Acres, names of developments and approval dates. Acres will be the variable used to generate ESAL values. However, we also need to breakdown the data based on land uses.

One must add a field to the attribute table and arbitrarily name it SF (square feet) to convert Acres to SF. This can be accomplished by the following: Right click on the field > click on field calculator > SF= 43560*Acres then Ok. The other obstacle is that there is no column that states which type of development this is so a manual inspection of each name of development by googling each name to determine the activities associated with the development, a column named: “category” was then added to the attributes table and the results came out like this:

A- 85 inputs: Residential development

B- 5 inputs: Other development:

  i. Country club.
  ii. Cemetery.
  iii. Fire Station.
  iv. 2 unknown inputs

C- 1 input: Industrial development: Robbert Madison Industries

D- 2 inputs: Commercial development: “Pensco Trust” and “Braun Commercial”

The next step is to break the July14-July15 shapefile into 4 different shapefiles in terms of land uses, this can be down the same way July14-July15 was extracted from the original shapefile. Each new shapefile is now a polygon based shapefile, in order to run the network analyst tool, each shapefile needs to be a point based shapefile. Switching from polyline to point can be done following these steps:

The tool is found in: ArcToolbox > Data Management Tools > Features > Feature to Point

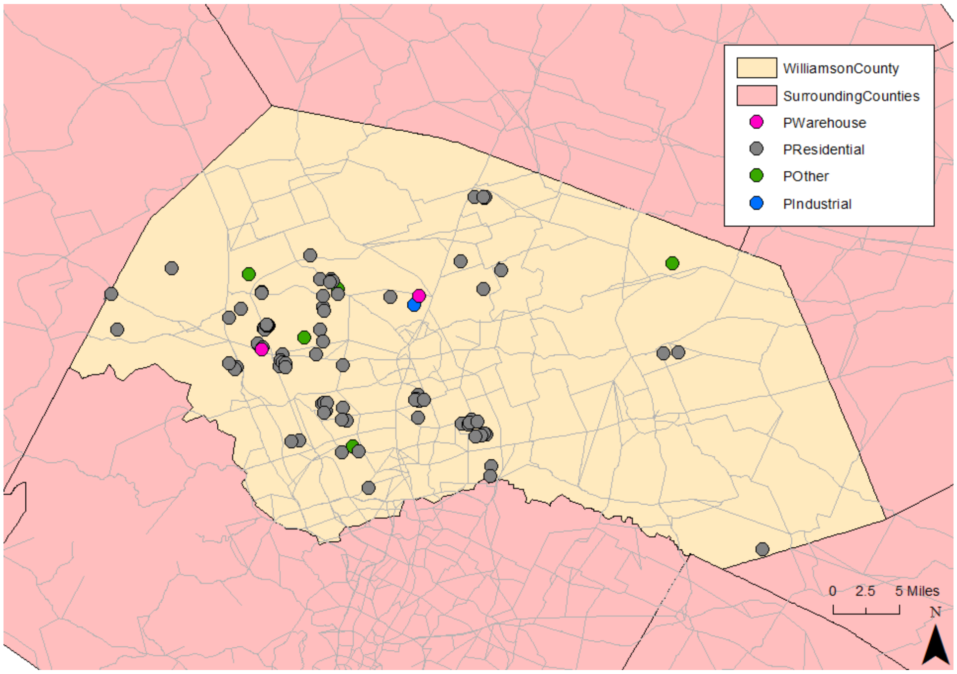
Input Features: Residential

Output: Presidential

RUN

Now Industrial, Warehouse and Other should be converted in the same manner. The model now should look like this.

Figure 29: Point location of land developments



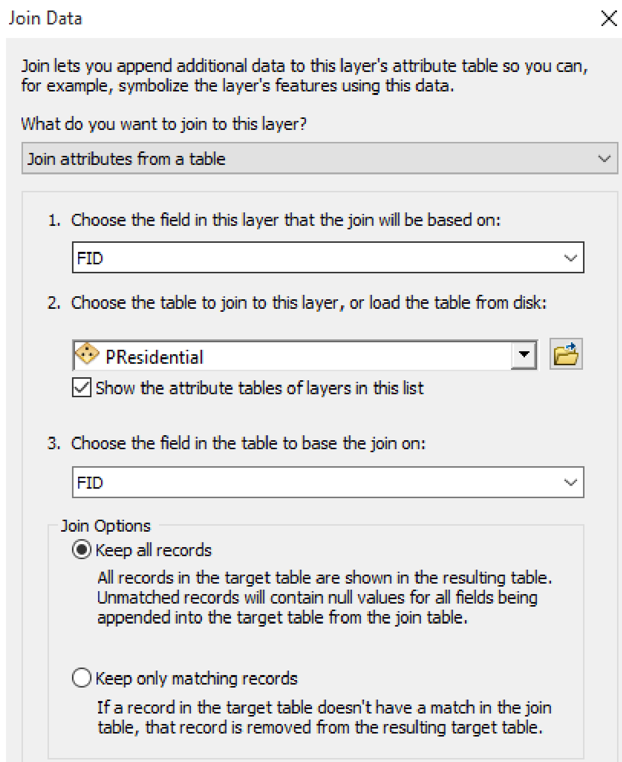
The next step is to find the shortest paths that trucks most likely will follow. Network Analyst tool is now to be used, following the same step from the Oil and Gas model will lead to 2 new shapefiles in the model. Land uses category shapefiles will be the Incidents in this model, but the missing piece of the puzzle is where are the trucks travelling to/from? The best assumption to be made at this point is that trucks most likely going to travel State Highways then to their destinations, or they might come from their origins thru State Highways then using local roads to their destinations. Finding the shortest path between the incidents and the State Highway junctions can be done in the following steps:

TexasRoads contains the breakdown of the streets based on their classification. Manually select streets that are Interstate highways, State Highways or US highways (IH, SH and US) and export this layer. TexasRoads_Junctions contains all the junctions in the

State of Texas. Clip The shapefile based on the Williamson county boundaries to show junctions located in Williamson only. Now we are only concerned with junctions that are on the State Highways. ArcMap main window top bar > Customize > Toolbars > Editor > Start Editing. Now manually delete all the junctions that are not included on the State Highway shapefile. We are now left with points that represents junctions with State Highway and the model is ready for network analysis.

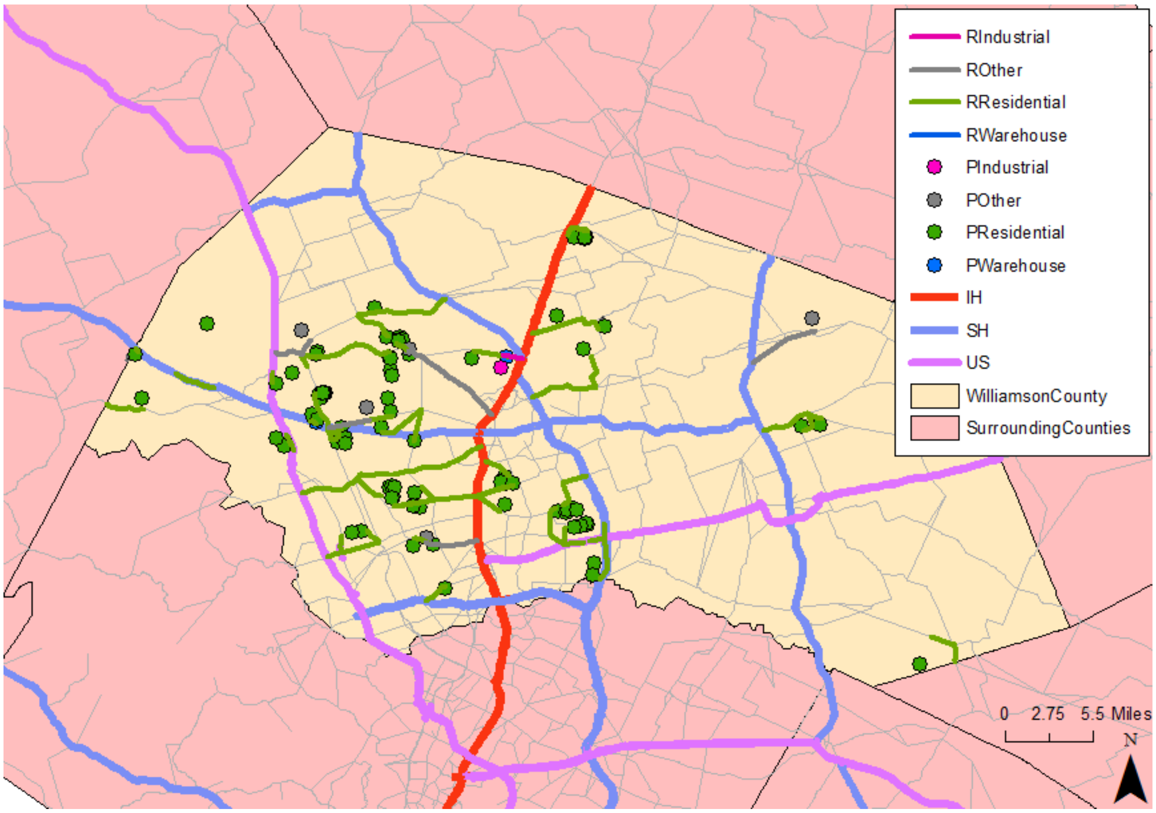
Loading PResidential shapfile as incidents, and TexasRoads_Junctions as facilities and running the Network Analyst closest facility tool will generate routes connecting Residential developments to the nearest State Highway. The same method should be done for all other lands uses. Export each route into a shapefile and name the routes RResidential, RIndustrial, RWarehouse and ROther. The routes now have attribute tables that are missing their SF fields. Right click on Residential > Joins and Relates > Join… Figure 30 shows what the join window must look like.

Figure 30: Join data window inputs: to join routes to points' attribute tables.



The same joining method must be followed for all the Routes in order to have the SF field included in the analysis. The next step is to save all the data inputs in one file in Catalog, then export the routes as new shapefiles to have the joined values connected permanently. Figure 31 shows the output of Network Analyst.

Figure 31: All inputs with output of shortest paths between developments and nearest state highway



At this step, all the inputs are in the model ready for the analysis. However, this model has two different truck trip generation tables. Production trips have an annual basis, while the construction trips will be instant, non-repeatable and can take up to one year than vanish. In Catalog, one might add another folder, copy and paste all the shapefiles and name it Production, rename the current folder Construction producing two models that can be separately manipulated. The only difference between the models will be the ESAL values. In the next steps are an explanation of how to add ESAL values for both models:

<u>Construction:</u>

Right click on RIndustrial > Attribute table > Add Field > ESAL (Double). Now navigate to the ESAL field right click > Field Calculator > ESAL: (SF/1000)*2.449 then Ok. The equation is valid for ROther and RWarehouse. However, RResidential equation is ESAL: (SF*2/15000)*2.449. Now ArcMap will generate ESAL values based on the SF values. At this step we connect the truck trip generation tables that were built on 1000SF variables with routes built from ArcMap.

Production:

RIndustrial> ESAL: (SF/1000)*232.655

RWarehouse> ESAL: (SF/1000)* 269.39

RResidential> ESAL: (SF/1000)* 9.83

ROther was excluded from this model due to variations in the productions trip data.

Oil and Gas model Analysis Method 2 and 3 would be done now to determine locations of maximum loadings. Following the same steps in the Oil and Gas models will have the following outputs.

Production output maps:

Figure 32: Spatial Analysis of the Production truck traffic (Method2)

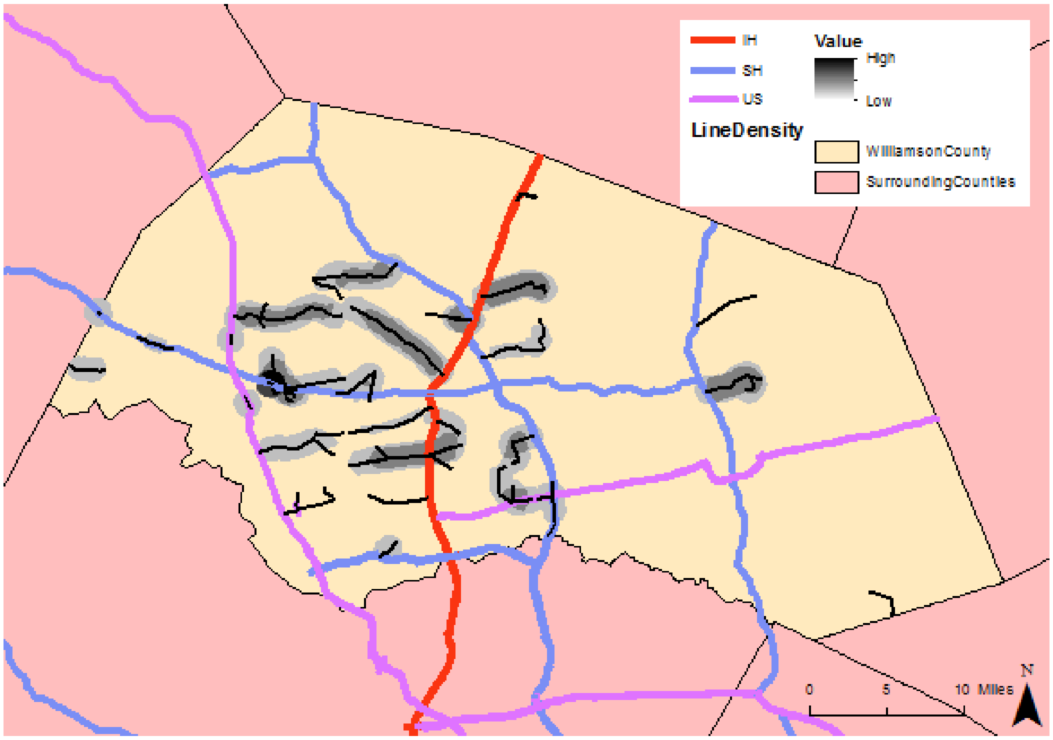
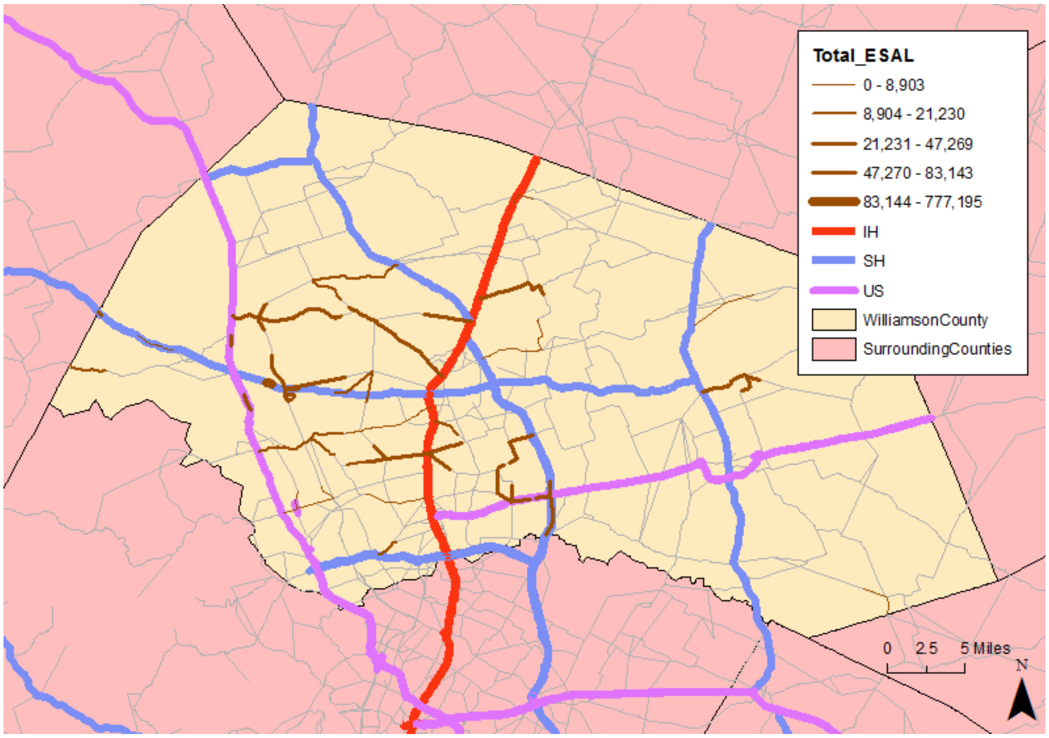


Figure 33: Production truck traffic Total ESAL values (Method3)



Construction output maps:

Figure 34: Spatial Analysis of the Construction truck traffic (Method2)

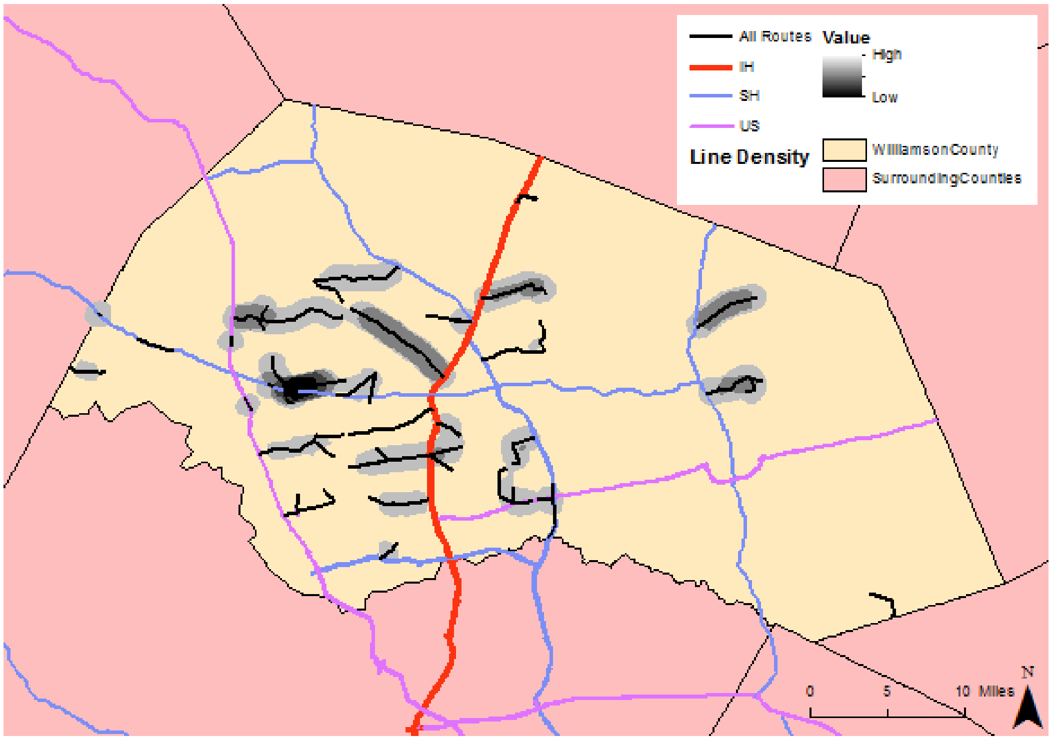
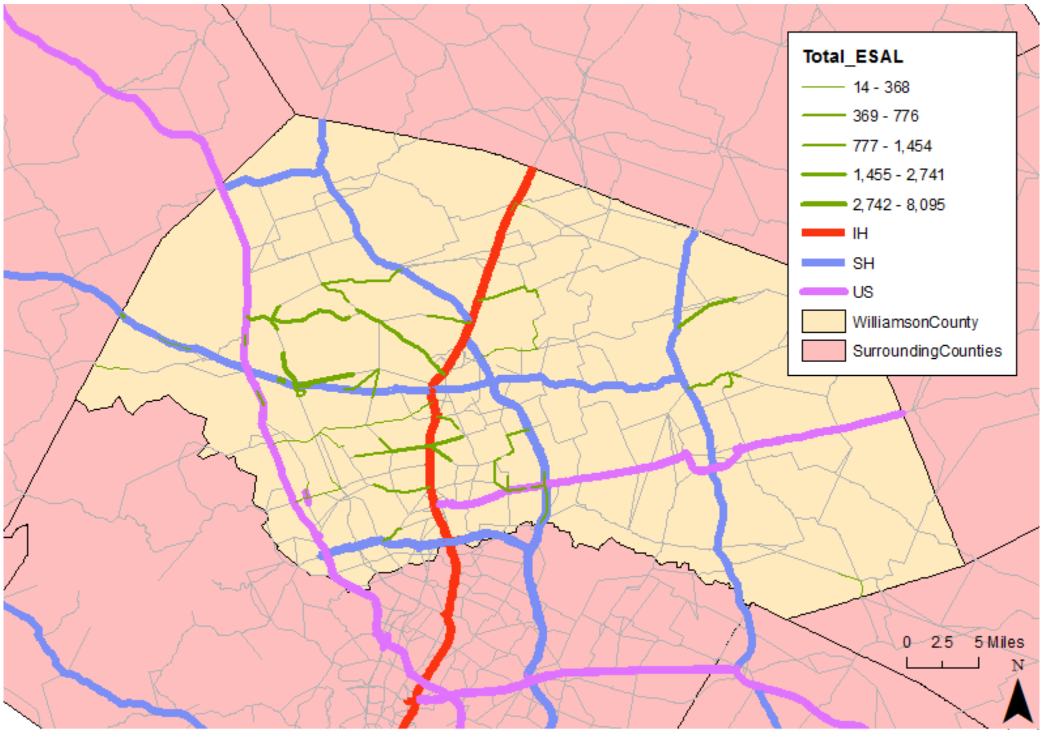


Figure 35: Construction truck traffic Total ESAL values (Method3)



CHAPTER 5: Discussion

This model predicts truck trips and associated ESAL values for specific highways resulting from land use changes including land development, re-development or mining activities. The model output identifies routes that represent the truck travel routes and ESAL values associated with that trip route. Different trip purposes generate trips overlapping or travelling in different directions. The model offers three analysis methods and ArcGIS provides the tools for users to build the desired analysis.

Analysis method #1: shows all the routes in the model, each route is assigned a specific width and color, meaning that each trip route associated with a specific ESAL for its trips can have a color and width. In the Austin District petroleum case study, only 3 ESAL values for 2 study periods were used, leading to a total of 6 values of ESALs assigned to each trip route. Flexibility of this case study is high compared to the Williamson county case study, since it has less variability of ESAL values, only 3 different ESAL values were included. This is due to the fact that ESAL values were only dependent on the travel activity, in this case it was water, disposal and quarry based trips. On the other hand, Williamson county model's ESAL values were dependent on area size which produced a huge variation of ESAL values and automatically eliminated the feasibility of analysis method #1. This analysis method is basic and does not require extensive knowledge or software skills. The output of this method can interoperated by manually adding each overlapping route's ESAL value to find the sum for the intersected segment.

Analysis method #2: This analysis method saves time for the user in manually looking into each segment, and identifying the "critical" segments. This is based on spatial analysis of ESALs of overlapping routes that have high total numbers of ESALs. The method is ideal for users with moderate knowledge of the software, and provides an efficient way to manually add fewer segments and only focus on critical zones.

Analysis method #3: Although this analysis method can be hard for the user to implement in the software, it provides exact numbers of ESAL values from the first run. It is the most efficient process and works on both case study examples as it does not take into account effects of the variation in ESAL values and it automatically sums overlapping ESALs and single trip route ESALs.

The Austin District case study was the simplest form of implementing the model, it had all the inputs the model needed: TTGTs built on previous research and GIS data of origins and destinations. The analysis was made using three different methods. Depending on the user capabilities and desired output, one can choose any of the three methods.

The reason behind 3 Analysis methods is to provide accurate estimates of ESAL values and to make sure the analysis of the inputs was correctly made. By comparing the results from the three methods in for Austin District Case Study: we find out that the critical segments are all in Lee County and have an estimate of 120,000 ESALs. This was predictable due to the abundance of oil wells in Lee county, compared to Caldwell and Bastrop Counties. The model successfully predicted the linear relationship of oil wells and route loadings, but the problem occurs, as stated above, truck loading has a non-linear relationship with pavement life-performance decrease. The more oil wells, the more overloading, the more rapid the decrease in pavement service life. However, Lee county officials are aware of the high numbers of oil wells, but are not exactly aware of where are the routes that are going to be damaged. The model predicted these routes, and also provided estimates of how many additional ESALs these oil wells are going to add to the existing traffic loadings.

Both analysis methods for Williamson County led to the prediction of extremely heavy locations with loadings up to 750,000 ESALs. These heavy loadings were generated in production traffic for building a “Braun Commercial” warehouse. The warehouse lot size is 2,836,211 square feet. This warehouse will add 750,000 ESALs every year to the pavement associated with linking it to the nearest heavy duty highway, , this loading route was successfully captured in this model which proves that with the implementation of an Easy-to-use, cost-effective tool not only Williamson county or Austin District can benefit from, every state, city and county officials can use this system. However, these numbers can vary depending on the assumptions made, but the concept of the two models remains valid for capturing unusual extremely high truck traffic loading.

CHAPTER 6: Conclusions

The Early Warning System model was developed based on current research gaps of predicting land use changes truck impacts on pavement. Various studies generated tools and methods to save money on pavement. Little interest was shown on implementing GIS software to identify locations on where most damages are occurring. By following land use changes, it was found that most land use changes generate truck traffic associated with their activities of construction and production. This truck traffic can be heavy and unexpected for when first designing the pavement. One of the previous research gaps is linking the GIS source with Truck Trip Generation to forecast locations of heavy loadings. By using ArcGIS, linking GIS data by their type to the nearest predicted truck destination or origin can be made by finding the shortest path routes, that trucks are most likely to follow.

On this concept, two case studies were built:

1- <u>Oil and Gas Growth case</u>: Austin District model was an example of a model where GIS data for both the origins and destinations for the trucks were known, The Oil and Gas Model was built for the Austin TxDOT district area for two periods of analysis, June-August and September-December of 2014. The model used oil well permits data to forecast routes between oil wells and origins/destinations of facilities servicing the construction of an oil well. Production traffic was neglected on this case because of the low traffic compared to construction, and the heavy construction traffic will happen before productions nonetheless. In this model results: Lee county had a segment of additional 120,000 ESALs on the pavement, this additional ESALs were definitely not accounted for when designing the pavement, as this segment is not in an industrial area or near an urban city where it is expected to have high-level loadings, the segment is in a rural area where most of the streets are designed based on the expectation of medium to low loadings.

2- Urban Growth case: Williamson county model was an example where only origins or only destinations were known. The case study period was determined to be a year, from July 2014 to July 2015. This was assumed based on the fact that building development need on average a year to complete, in terms of construction traffic. The model had two output maps, one for production traffic and the other for construction truck traffic. In this case, land developments TTGTs were based on 1000 square foot area size. So for each 1000 square foot there is a certain truck rate associated with it. The solution for the absence of origins or destinations GIS data, or predictions, was solved based on connecting land development to the nearest state highway to forecast truck trips routes. This was based on the assumption that state highways are usually designed and maintained to hold high level of loadings compared to local streets or county level highways.

Future research can be done in order to optimize the model. In general, less assumptions lead to a better model. in this thesis, the mystery of where the trucks are travelling was solved based on GIS software and estimation of origins and destinations.

however, in the urban growth model, a need for further research is clear based on the assumption that trucks will travel to and from the nearest highway. The assumption could be valid for calculation purposes, but in reality, this might not be ideal. More data lead to better models as well, the more the data is collected about locations and destinations of truck travel, the easier this model will be to implement. Collecting data is not the only way of getting GIS data, there could be other assumptions that are valid but were not accounted for or missed in the development this thesis. It would be ideal to further investigate this basic model that has a very strong base. The model predicted truck travel in relation to two land use changes, namely Oil and Gas and Urban growth, whereas the goal is for the model to work with any land use changes other than the two, as long as there is GIS-base geographic data or location information, and TTGTs, the model should be able to predict routes and loadings of trucks.

Appendix

From TRRC Website:

Oil Wells Excel Data:

A- First Period (June to August)

(Operator Name, Lease Name, District Well Name, Total Depth and Amend columns were excluded from the files)

ID	X	Y	API NO.	County	Filing Purpose
1	-97.08662900	30.09179300	2131634	BASTROP	New Drill
2	-97.26206900	30.21971000	2131635	BASTROP	New Drill
3	-97.38373400	30.02018600	2131636	BASTROP	New Drill
4	-97.761806	29.770419	5532943	CALDWELL	Reenter
5	-97.630968	29.711973	5535061	CALDWELL	New Drill
6	-97.68657	29.860694	5533307	CALDWELL	Reenter
7	-97.69953	29.843777	5533207	CALDWELL	Reenter
8	-97.713864	29.826467	5533444	CALDWELL	Reenter
9	-97.503944	29.928296	5535075	CALDWELL	New Drill
10	-97.520155	29.930807	5535081	CALDWELL	New Drill
11	-97.6351	29.79616	5535077	CALDWELL	New Drill
12	-97.64104	29.796849	5535078	CALDWELL	New Drill
13	-97.635512	29.805114	5535079	CALDWELL	New Drill
14	-97.596832	29.84088	5535080	CALDWELL	New Drill

15	-97.600229	29.761458	5535025	CALDWELL	Recompletion
16	-97.596677	29.840638	5535082	CALDWELL	New Drill
17	-97.518275	29.948145	5535084	CALDWELL	New Drill
18	-97.629919	29.81039	5535083	CALDWELL	New Drill
19	-97.60719	29.839367	5535086	CALDWELL	New Drill
20	-97.624821	29.820149	5535087	CALDWELL	New Drill
21	-97.744907	29.788336	5532791	CALDWELL	Reenter
22	-97.742139	29.79072	5532649	CALDWELL	Reenter
23	-96.825001	30.214699	28732637	LEE	New Drill
24	-96.740548	30.231031	28732645	LEE	New Drill
25	-96.993072	30.272004	28732646	LEE	New Drill
26	-96.994113	30.270966	28732647	LEE	New Drill
27	-96.936861	30.317956	28732650	LEE	New Drill
28	-96.937913	30.316956	28732651	LEE	New Drill
29	-96.938985	30.315881	28732652	LEE	New Drill
30	-96.90255	30.313603	28732654	LEE	New Drill
31	-96.874291	30.289352	28732653	LEE	New Drill
32	-96.892594	30.348273	28732655	LEE	New Drill
33	-96.839988	30.162136	28732600	LEE	Recompletion
34	-96.995406	30.269718	28732656	LEE	New Drill
35	-96.932685	30.347782	28732657	LEE	New Drill
36	-96.934402	30.347245	28732658	LEE	New Drill
37	-96.934767	30.345541	28732659	LEE	New Drill

38	-96.951858	30.290004	28732603	LEE	Field Transfer
39	-96.918564	30.322333	28732660	LEE	New Drill
40	-96.917459	30.323361	28732661	LEE	New Drill
41	-96.981255	30.078648	28732227	LEE	Recompletion
42	-96.847617	30.31357	28732662	LEE	New Drill
43	-97.034084	30.107071	28732287	LEE	Recompletion
44	-96.962351	30.261968	28732664	LEE	New Drill
45	-96.954283	30.337982	28732667	LEE	New Drill
46	-96.955356	30.336889	28732668	LEE	New Drill
47	-96.956386	30.335889	28732669	LEE	New Drill
48	-96.969604	30.269103	28732663	LEE	New Drill
49	-97.061507	30.273884	28732670	LEE	New Drill
50	-96.959369	30.279276	28732636	LEE	New Drill
51	-96.972136	30.311922	28732671	LEE	New Drill
52	-96.973166	30.310921	28732672	LEE	New Drill
53	-96.97426	30.309902	28732673	LEE	New Drill
54	-96.997778	30.284854	28732674	LEE	New Drill
55	-97.004194	30.268102	28732675	LEE	New Drill
56	-97.005224	30.267046	28732676	LEE	New Drill
57	-96.962737	30.075138	28732679	LEE	New Drill
58	-96.999752	30.267027	28732677	LEE	New Drill
59	-96.41917	30.534547	5133795	BURLESON	New Drill
60	-96.662738	30.545861	5133796	BURLESON	New Drill

61	-96.669405	30.546627	5133797	BURLESON	New Drill
62	-96.675476	30.606962	5133798	BURLESON	New Drill
63	-96.622	30.438866	5133799	BURLESON	New Drill
64	-96.464067	30.536408	5133800	BURLESON	New Drill
65	-96.781317	30.614331	5133718	BURLESON	New Drill
66	-96.688283	30.402277	5130868	BURLESON	Recompletion
67	-96.579336	30.380517	5133804	BURLESON	New Drill
68	-96.561109	30.400394	5133802	BURLESON	New Drill
69	-96.618086	30.719042	5133801	BURLESON	New Drill
70	-96.869156	30.529603	5130418	BURLESON	Reenter
71	-96.589476	30.551608	5133803	BURLESON	New Drill
72	-96.664698	30.494585	5133783	BURLESON	New Drill
73	-96.868082	30.497586	5133773	BURLESON	New Drill
74	-96.816491	30.547423	5133805	BURLESON	New Drill
75	-96.521059	30.499948	5133806	BURLESON	New Drill
76	-96.519954	30.500936	5133807	BURLESON	New Drill
77	-96.518848	30.501924	5133808	BURLESON	New Drill
78	-96.88453	30.495818	5133761	BURLESON	New Drill
79	-96.731157	30.460332	5133809	BURLESON	New Drill
80	-96.363428	30.541814	5133810	BURLESON	New Drill
81	-96.375128	30.5439	5133811	BURLESON	New Drill
82	-96.679564	30.534017	5133812	BURLESON	New Drill
83	-96.510022	30.494906	5133781	BURLESON	New Drill

84	-96.511138	30.493928	5133815	BURLESON	New Drill
85	-96.715813	30.440465	5133813	BURLESON	New Drill
86	-96.744079	30.465628	5133814	BURLESON	New Drill
87	-96.753244	30.590118	5133820	BURLESON	New Drill
88	-96.407995	30.48661	5133817	BURLESON	New Drill
89	-96.434101	30.49487	5133818	BURLESON	New Drill
90	-96.410284	30.484723	5133819	BURLESON	New Drill
91	-96.652158	30.393408	5133821	BURLESON	New Drill
92	-96.436361	30.492937	5133816	BURLESON	New Drill
93	-96.366332	30.519468	5133825	BURLESON	New Drill
94	-96.658603	30.347383	5133822	BURLESON	New Drill
95	-96.356151	30.522147	5133828	BURLESON	New Drill
96	-96.357114	30.520617	5133829	BURLESON	New Drill
97	-96.604263	30.713474	5133823	BURLESON	New Drill
98	-96.465295	30.526039	5133826	BURLESON	New Drill
99	-96.358947	30.519982	5133830	BURLESON	New Drill
100	-96.430674	30.45155	5133831	BURLESON	New Drill
101	-96.58449	30.683917	5133827	BURLESON	New Drill
102	-96.653648	30.573632	5133835	BURLESON	New Drill
103	-96.519511	30.454457	5133832	BURLESON	New Drill
104	-96.517865	30.455913	5133833	BURLESON	New Drill
105	-96.516219	30.457368	5133834	BURLESON	New Drill
106	-96.909483	29.736361	14933358	FAYETTE	New Drill

107	-97.163851	29.725281	14933359	FAYETTE	New Drill
108	-97.161545	29.722699	14933360	FAYETTE	New Drill
109	-97.080724	29.799426	14933363	FAYETTE	New Drill
110	-97.113425	29.62889	14933362	FAYETTE	New Drill
111	-97.168633	29.703293	14933352	FAYETTE	New Drill
112	-97.191771	29.708908	14932140	FAYETTE	Recompletion
113	-97.130746	29.675837	14933367	FAYETTE	New Drill
114	-97.130621	29.674289	14933368	FAYETTE	New Drill
115	-97.130842	29.672967	14933371	FAYETTE	New Drill
116	-97.148156	29.657569	14933372	FAYETTE	New Drill
117	-97.146576	29.656373	14933373	FAYETTE	New Drill
118	-97.09071	29.611556	14933365	FAYETTE	New Drill
119	-97.088794	29.611472	14933366	FAYETTE	New Drill
120	-97.162724	29.683001	14933354	FAYETTE	New Drill
121	-97.211558	29.7935	14933369	FAYETTE	New Drill
122	-97.133239	29.816304	14933264	FAYETTE	New Drill
123	-97.273961	29.773311	14933370	FAYETTE	New Drill
124	-97.003712	29.692988	14933374	FAYETTE	New Drill
125	-97.066759	29.820729	14933334	FAYETTE	New Drill
126	-97.097391	29.629457	14933307	FAYETTE	New Drill
127	-97.095664	29.629215	14933375	FAYETTE	New Drill
128	-97.119335	29.666449	14933328	FAYETTE	New Drill
129	-97.09393	29.629249	14933376	FAYETTE	New Drill

130	-97.0922	29.629285	14933377	FAYETTE	New Drill
131	-97.162724	29.683001	14933354	FAYETTE	New Drill
132	-97.086066	29.629999	14933353	FAYETTE	New Drill
133	-96.746964	29.895771	14933378	FAYETTE	New Drill
134	-97.312847	29.405455	17733356	GONZALES	New Drill
135	-97.698465	29.210873	17733371	GONZALES	New Drill
136	-97.34354	29.59227	17733277	GONZALES	New Drill
137	-97.205558	29.676783	17733373	GONZALES	New Drill
138	-97.307109	29.403304	17733358	GONZALES	New Drill
139	-97.37056	29.406497	17733376	GONZALES	New Drill
140	-97.373271	29.404861	17733378	GONZALES	New Drill
141	-97.422829	29.557362	17733382	GONZALES	New Drill
142	-97.651232	29.342182	17733372	GONZALES	New Drill
143	-97.371441	29.405963	17733375	GONZALES	New Drill
144	-97.701134	29.37955	17733288	GONZALES	New Drill
145	-97.63192	29.32688	17733354	GONZALES	New Drill
146	-97.630612	29.330107	17733355	GONZALES	New Drill
147	-97.372468	29.405541	17733377	GONZALES	New Drill
148	-97.234817	29.537508	17733389	GONZALES	New Drill
149	-97.638651	29.375417	17733383	GONZALES	New Drill
150	-97.468566	29.246863	17733352	GONZALES	New Drill
151	-97.567801	29.181009	17733385	GONZALES	New Drill
152	-97.567416	29.181608	17733386	GONZALES	New Drill

153	-97.566759	29.18196	17733387	GONZALES	New Drill
154	-97.615309	29.352049	17733384	GONZALES	New Drill
155	-97.658761	29.285695	17733381	GONZALES	New Drill
156	-97.220479	29.532277	17733388	GONZALES	New Drill
157	-97.330335	29.629744	17733398	GONZALES	New Drill
158	-97.234158	29.565854	17733390	GONZALES	New Drill
159	-97.58234	29.211646	17733392	GONZALES	New Drill
160	-97.581898	29.212387	17733393	GONZALES	New Drill
161	-97.581481	29.213114	17733395	GONZALES	New Drill
162	-97.516864	29.251732	17733394	GONZALES	New Drill
163	-97.516389	29.252432	17733396	GONZALES	New Drill
164	-97.515947	29.253212	17733397	GONZALES	New Drill
165	-97.204732	29.61815	17733400	GONZALES	New Drill
166	-97.204661	29.616728	17733399	GONZALES	New Drill
167	-97.364383	29.443821	17732791	GONZALES	Recompletion
168	-97.390519	29.258283	17732686	GONZALES	Field Transfer
169	-97.387894	29.258414	17732684	GONZALES	Field Transfer
170	-97.670613	29.25379	17733404	GONZALES	New Drill
171	-97.160269	29.605171	17733401	GONZALES	New Drill
172	-97.159135	29.605784	17733402	GONZALES	New Drill
173	-97.158362	29.606658	17733403	GONZALES	New Drill
174	-97.389767	29.258872	17732683	GONZALES	Field Transfer
175	-97.391942	29.258474	17732682	GONZALES	Field Transfer

176	-97.432652	29.302562	17733406	GONZALES	New Drill
177	-97.430093	29.303078	17733407	GONZALES	New Drill
178	-97.422874	29.311158	17733410	GONZALES	New Drill
179	-97.686382	29.306103	17733391	GONZALES	New Drill
180	-97.262716	29.387668	17733421	GONZALES	New Drill
181	-97.303776	29.403922	17733415	GONZALES	New Drill
182	-97.302146	29.404369	17733416	GONZALES	New Drill
183	-97.300543	29.404808	17733417	GONZALES	New Drill
184	-97.504146	29.339585	17731914	GONZALES	Recompletion
185	-97.534903	29.192578	17733419	GONZALES	New Drill
186	-97.535819	29.192142	17733420	GONZALES	New Drill
187	-97.427418	29.303728	17733408	GONZALES	New Drill
188	-97.520094	29.249568	17733418	GONZALES	New Drill
189	-97.263589	29.387161	17733422	GONZALES	New Drill
190	-97.264631	29.386947	17733423	GONZALES	New Drill
191	-97.265717	29.386197	17733424	GONZALES	New Drill
192	-97.421749	29.31305	17733409	GONZALES	New Drill
193	-97.580951	29.213819	17733425	GONZALES	New Drill
194	-97.580455	29.214513	17733426	GONZALES	New Drill
195	-97.580041	29.215248	17733427	GONZALES	New Drill
196	-97.612318	29.354328	17733443	GONZALES	New Drill
197	-97.305553	29.403736	17733414	GONZALES	New Drill
198	-97.317475	29.341779	17733430	GONZALES	New Drill

199	-97.316791	29.342199	17733431	GONZALES	New Drill
200	-97.413955	29.373581	17733319	GONZALES	New Drill
201	-97.409763	29.373126	17733448	GONZALES	New Drill
202	-97.408822	29.37517	17733449	GONZALES	New Drill
203	-97.683962	29.30837	17733380	GONZALES	New Drill
204	-97.299315	29.326131	17733436	GONZALES	New Drill
205	-97.300114	29.325689	17733437	GONZALES	New Drill
206	-97.300868	29.325208	17733438	GONZALES	New Drill
207	-97.226889	29.571817	17733441	GONZALES	New Drill
208	-97.204068	29.557387	17733439	GONZALES	New Drill
209	-97.530417	29.215544	17733440	GONZALES	New Drill
210	-97.318842	29.340621	17733429	GONZALES	New Drill
211	-97.356209	29.296518	17733446	GONZALES	New Drill
212	-97.651232	29.342182	17733372	GONZALES	New Drill
213	-97.657535	29.288521	17733434	GONZALES	New Drill
214	-97.399277	29.383058	17733450	GONZALES	New Drill
215	-97.400152	29.382436	17733451	GONZALES	New Drill
216	-97.400952	29.381886	17733454	GONZALES	New Drill
217	-97.353982	29.412013	17733452	GONZALES	New Drill
218	-97.353085	29.412477	17733453	GONZALES	New Drill
219	-97.352215	29.412833	17733455	GONZALES	New Drill
220	-97.528424	29.199034	17733432	GONZALES	New Drill
221	-97.528895	29.19801	17733433	GONZALES	New Drill

222	-97.356775	29.299378	17733442	GONZALES	New Drill
223	-97.39181	29.367645	17733444	GONZALES	New Drill
224	-97.392378	29.366942	17733445	GONZALES	New Drill
225	-97.355542	29.296937	17733447	GONZALES	New Drill
226	-97.466496	29.274303	17733156	GONZALES	New Drill
227	-97.46736	29.274009	17733161	GONZALES	New Drill
228	-97.456182	29.251099	17733160	GONZALES	New Drill
229	-97.457149	29.250774	17733162	GONZALES	New Drill
230	-97.465633	29.274598	17733459	GONZALES	New Drill
231	-97.512195	29.209439	17733462	GONZALES	New Drill
232	-97.237235	29.453731	17733458	GONZALES	New Drill
233	-97.144532	29.606771	17733465	GONZALES	New Drill
234	-97.144431	29.608087	17733466	GONZALES	New Drill
235	-97.743209	29.608455	18733630	GUADALUPE	New Drill
236	-98.043043	29.419234	18733631	GUADALUPE	New Drill
237	-97.707638	29.655179	18733632	GUADALUPE	New Drill
238	-98.101658	29.416845	18733633	GUADALUPE	New Drill
239	-98.038994	29.395743	18733635	GUADALUPE	New Drill
240	-98.038994	29.395743	18733636	GUADALUPE	New Drill
241	-96.989629	30.623836	33134884	MILAM	New Drill
242	-96.99613	30.617336	33134882	MILAM	New Drill
243	-96.99753	30.623236	33134883	MILAM	New Drill
244	-96.940453	30.793792	33134891	MILAM	New Drill

245	-96.939654	30.793341	33134892	MILAM	New Drill
246	-96.991652	30.632533	33134885	MILAM	New Drill
247	-96.991391	30.631794	33134887	MILAM	New Drill
248	-96.991118	30.631147	33134890	MILAM	New Drill
249	-96.991877	30.633085	33134889	MILAM	New Drill
250	-96.962545	30.659087	33134896	MILAM	New Drill
251	-96.992427	30.632719	33134888	MILAM	New Drill
252	-96.992202	30.632044	33134886	MILAM	New Drill
253	-96.917463	30.605552	33134895	MILAM	New Drill
254	-96.901081	30.632008	33134897	MILAM	New Drill
255	-97.058168	30.710578	33134898	MILAM	New Drill
256	-97.036558	30.958374	33134899	MILAM	New Drill
257	-97.050618	30.705965	33134904	MILAM	New Drill
258	-97.053632	30.710056	33134905	MILAM	New Drill
259	-97.054363	30.709916	33134906	MILAM	New Drill
260	-96.776666	30.681111	33134879	MILAM	New Drill
261	-97.012116	30.679797	33134915	MILAM	New Drill
262	-96.939302	30.79412	33134902	MILAM	New Drill
263	-96.938698	30.795833	33134903	MILAM	New Drill
264	-96.938004	30.798468	33134913	MILAM	New Drill
265	-96.93933	30.799573	33134914	MILAM	New Drill
266	-96.715055	30.209004	47731021	WASHINGTON	New Drill

B- Second Period (September to November)

ID	X	Y	API NO.	County	Filing Purpose
1	-97.3714070	30.0239530	2131637	BASTROP	New Drill
2	-97.2685180	30.2186310	2131638	BASTROP	New Drill
3	-97.1041910	30.0318530	2131639	BASTROP	New Drill
4	-97.0859800	30.1001160	2131640	BASTROP	New Drill
5	-97.1383490	30.1865240	2131572	BASTROP	Recompletion
6	-97.7253510	29.8184860	5535088	CALDWELL	New Drill
7	-97.7569580	29.7784520	5533872	CALDWELL	Reenter
8	-97.6111320	29.8241460	5535089	CALDWELL	New Drill
9	-97.6909970	29.7711510	5534808	CALDWELL	Recompletion
10	-97.6760410	29.7700900	5535090	CALDWELL	New Drill
11	-97.5876570	29.8425920	5505300	CALDWELL	Recompletion
12	-97.6760630	29.7700900	5535090	CALDWELL	New Drill
13	-97.5077270	29.9305150	5535091	CALDWELL	New Drill
14	-97.6712990	29.7725670	5535092	CALDWELL	New Drill
15	-97.5156240	29.9244530	5535094	CALDWELL	New Drill
16	-96.9327050	30.3477630	28732657	LEE	New Drill
17	-96.9343780	30.3472070	28732658	LEE	New Drill
18	-97.0105530	30.3331140	28732680	LEE	New Drill
19	-97.0013480	30.2776310	28732678	LEE	New Drill
20	-96.8664000	30.2708670	28732681	LEE	New Drill

21	-96.9805340	30.2760930	28732691	LEE	New Drill
22	-96.9817140	30.2750730	28732682	LEE	New Drill
23	-96.9827220	30.2740910	28732683	LEE	New Drill
24	-96.9837520	30.2730530	28732688	LEE	New Drill
25	-96.9848470	30.2720340	28732689	LEE	New Drill
26	-96.9856190	30.2709220	28732687	LEE	New Drill
27	-96.9869500	30.2699770	28732690	LEE	New Drill
28	-96.9736460	30.3074790	28732684	LEE	New Drill
29	-96.9747830	30.3065160	28732685	LEE	New Drill
30	-96.9751480	30.3049410	28732686	LEE	New Drill
31	-96.8574740	30.2634540	28732692	LEE	New Drill
32	-96.8607570	30.2604880	28732693	LEE	New Drill
33	-96.8590830	30.2619710	28732694	LEE	New Drill
34	-96.7958910	30.3331880	28730364	LEE	Recompletion
35	-96.9759420	30.1617830	28732445	LEE	Reclass
36	-96.9275330	30.0750670	28732695	LEE	New Drill
37	-96.9986660	30.2106380	28732639	LEE	New Drill
38	-96.9976140	30.2116020	28732638	LEE	New Drill
39	-96.8830520	30.3373180	28732696	LEE	New Drill
40	-96.8842320	30.3363370	28732697	LEE	New Drill
41	-96.8854120	30.3354480	28732698	LEE	New Drill
42	-96.9041440	30.2947330	28732700	LEE	New Drill
43	-96.9027070	30.2954560	28732699	LEE	New Drill

44	-96.9013120	30.2961780	28732703	LEE	New Drill
45	-96.8812710	30.1203650	28732534	LEE	Recompletion
46	-96.9827440	30.2915460	28732701	LEE	New Drill
47	-96.9837950	30.2905090	28732702	LEE	New Drill
48	-96.9041230	30.2947330	28732700	LEE	New Drill
49	-96.9041230	30.2947330	28732699	LEE	New Drill
50	-96.8650920	30.2368180	28730581	LEE	Recompletion
51	-96.8899820	30.4355330	28732704	LEE	New Drill
52	-96.8812490	30.1203650	28732534	LEE	Recompletion
53	-96.9847610	30.2894340	28732705	LEE	New Drill
54	-96.5611010	30.4002640	05133802	BURLESON	New Drill
55	-96.4673520	30.5334080	05133824	BURLESON	New Drill
56	-96.4332560	30.5185850	05133836	BURLESON	New Drill
57	-96.4312600	30.5202850	05133837	BURLESON	New Drill
58	-96.6276410	30.3766090	05133838	BURLESON	New Drill
59	-96.5855410	30.6817620	05133839	BURLESON	New Drill
60	-96.5873220	30.6808580	05133840	BURLESON	New Drill
61	-96.3806630	30.5351640	05133841	BURLESON	New Drill
62	-96.3672950	30.5189170	05133842	BURLESON	New Drill
63	-96.3706850	30.5177900	05133843	BURLESON	New Drill
64	-96.6601920	30.5257940	05133845	BURLESON	New Drill
65	-96.6576820	30.6182970	05133844	BURLESON	New Drill
66	-96.5530110	30.4837340	05133846	BURLESON	New Drill

67	-96.7684250	30.5151090	05133847	BURLESON	New Drill
68	-96.6524460	30.3934900	05133849	BURLESON	New Drill
69	-96.4900760	30.4811820	05133850	BURLESON	New Drill
70	-96.4890670	30.4822550	05133851	BURLESON	New Drill
71	-96.4879730	30.4832350	05133853	BURLESON	New Drill
72	-96.4868360	30.4842700	05133852	BURLESON	New Drill
73	-96.4713860	30.4335720	05133855	BURLESON	New Drill
74	-96.4695410	30.4352000	05133856	BURLESON	New Drill
75	-96.4676310	30.4369020	05133857	BURLESON	New Drill
76	-96.5067480	30.4648520	05133854	BURLESON	New Drill
77	-96.5049240	30.4664980	05133860	BURLESON	New Drill
78	-96.5029720	30.4681810	05133861	BURLESON	New Drill
79	-96.4657640	30.4385860	05133858	BURLESON	New Drill
80	-96.4579750	30.3928980	05133859	BURLESON	New Drill
81	-96.4361960	30.4938490	05133862	BURLESON	New Drill
82	-96.7721150	30.5144250	05133863	BURLESON	New Drill
83	-96.7736170	30.5119300	05133864	BURLESON	New Drill
84	-96.4379570	30.4922540	05133866	BURLESON	New Drill
85	-96.3627690	30.5195050	05133868	BURLESON	New Drill
86	-96.6334360	30.4022220	05133870	BURLESON	New Drill
87	-96.6651290	30.4075150	05133865	BURLESON	New Drill
88	-96.6204110	30.4913480	05133867	BURLESON	New Drill
89	-96.5864440	30.4015000	05133871	BURLESON	New Drill

90	-96.5606730	30.6078590	05133869	BURLESON	New Drill
91	-96.5572400	30.6093180	05133883	BURLESON	New Drill
92	-96.6521470	30.3933010	05133821	BURLESON	New Drill
93	-96.7618170	30.5912180	05133768	BURLESON	New Drill
94	-96.6524480	30.3854900	05133874	BURLESON	New Drill
95	-96.6480920	30.3893400	05133878	BURLESON	New Drill
96	-96.5884180	30.3995010	05133877	BURLESON	New Drill
97	-96.5907570	30.3973910	05133879	BURLESON	New Drill
98	-96.6380070	30.3977980	05133873	BURLESON	New Drill
99	-96.6355390	30.3999080	05133875	BURLESON	New Drill
100	-96.8411040	30.5116850	05133876	BURLESON	New Drill
101	-96.6772740	30.6462470	05133881	BURLESON	New Drill
102	-96.7133450	30.4888710	05133880	BURLESON	New Drill
103	-96.6316340	30.5654840	05133794	BURLESON	New Drill
104	-96.4655300	30.4662720	05133884	BURLESON	New Drill
105	-96.5279070	30.6050330	05133281	BURLESON	Recompletion
106	-96.5545360	30.6113860	05133882	BURLESON	New Drill
107	-96.4353820	30.5175450	05133885	BURLESON	New Drill
108	-96.3287370	30.4564330	05133886	BURLESON	New Drill
109	-96.7721600	30.5144210	05133863	BURLESON	New Drill
110	-96.7736170	30.5119300	05133864	BURLESON	New Drill
111	-96.7684250	30.5151090	05133847	BURLESON	New Drill
112	-96.8845340	30.4956930	05133761	BURLESON	Recompletion

113	-96.3806630	30.5351640	05133841	BURLESON	New Drill
114	-96.6462460	30.3455740	05133889	BURLESON	New Drill
115	-96.6444010	30.3473140	05133890	BURLESON	New Drill
116	-96.6425770	30.3488700	05133891	BURLESON	New Drill
117	-96.5793410	30.3803990	05133804	BURLESON	New Drill
118	-96.6407100	30.3505550	05133892	BURLESON	New Drill
119	-96.6389080	30.3522210	05133893	BURLESON	New Drill
120	-96.6452810	30.4897950	05133787	BURLESON	New Drill
121	-96.3806630	30.5351640	05133841	BURLESON	New Drill
122	-96.4268420	30.5297820	05130311	BURLESON	Recompletion
123	-96.4324420	30.5534740	05133746	BURLESON	New Drill
124	-96.5793410	30.3803990	05133804	BURLESON	New Drill
125	-96.3608810	30.5194120	05133894	BURLESON	New Drill
126	-96.3650010	30.5188950	05133896	BURLESON	New Drill
127	-96.6978310	30.4881860	05133897	BURLESON	New Drill
128	-96.4900760	30.4811820	05133850	BURLESON	New Drill
129	-96.4890670	30.4822550	05133851	BURLESON	New Drill
130	-96.4879730	30.4832350	05133853	BURLESON	New Drill
131	-96.4868360	30.4842700	05133852	BURLESON	New Drill
132	-96.6810720	30.5205580	05133779	BURLESON	New Drill
133	-96.6425770	30.3488700	05133891	BURLESON	New Drill
134	-96.4817730	30.4887410	05133898	BURLESON	New Drill
135	-96.4829110	30.4877980	05133899	BURLESON	New Drill

136	-96.4850780	30.4858200	05133901	BURLESON	New Drill
137	-96.3690780	30.5185070	05133902	BURLESON	New Drill
138	-96.3707300	30.5177670	05133843	BURLESON	New Drill
139	-96.3717170	30.5167320	05133903	BURLESON	New Drill
140	-96.5195170	30.4543050	05133832	BURLESON	New Drill
141	-96.5162770	30.4572460	05133834	BURLESON	New Drill
142	-97.1542570	29.8452500	14933294	FAYETTE	New Drill
143	-97.1229500	29.7729720	14933382	FAYETTE	New Drill
144	-97.1483340	29.7568980	14933379	FAYETTE	New Drill
145	-97.1576040	29.7469500	14933380	FAYETTE	New Drill
146	-97.1145820	29.7792300	14933381	FAYETTE	New Drill
147	-97.1588920	29.6670880	14933383	FAYETTE	New Drill
148	-97.1588700	29.6662300	14933384	FAYETTE	New Drill
149	-97.1553730	29.6643100	14933385	FAYETTE	New Drill
150	-97.1553080	29.6622770	14933386	FAYETTE	New Drill
151	-97.1552650	29.6602080	14933387	FAYETTE	New Drill
152	-97.1505450	29.6583620	14933388	FAYETTE	New Drill
153	-97.1519820	29.6581750	14933389	FAYETTE	New Drill
154	-97.1537420	29.6579700	14933390	FAYETTE	New Drill
155	-97.1552870	29.6576340	14933391	FAYETTE	New Drill
156	-97.1568530	29.6574670	14933392	FAYETTE	New Drill
157	-97.1184650	29.7766420	14932698	FAYETTE	Recompletion
158	-97.1481410	29.6574480	14933372	FAYETTE	New Drill

159	-97.1465750	29.6562920	14933373	FAYETTE	New Drill
160	-97.1929020	29.7084340	14933393	FAYETTE	New Drill
161	-96.9094890	29.7362740	14933358	FAYETTE	New Drill
162	-97.0303600	29.6630980	14933394	FAYETTE	New Drill
163	-97.0866220	30.0116300	14933395	FAYETTE	New Drill
164	-97.1318550	29.6711710	14933396	FAYETTE	New Drill
165	-97.1334430	29.6714130	14933398	FAYETTE	New Drill
166	-97.1350090	29.6716740	14933397	FAYETTE	New Drill
167	-97.0850560	29.8276970	14933293	FAYETTE	New Drill
168	-97.1278420	29.8434260	14933275	FAYETTE	New Drill
169	-97.1714870	29.6757390	14933399	FAYETTE	New Drill
170	-96.7457030	29.9117460	14933400	FAYETTE	New Drill
171	-97.0841330	29.6292880	14933401	FAYETTE	New Drill
172	-96.8836760	30.0689720	14933210	FAYETTE	Recompletion
173	-97.1201180	29.8071070	14933297	FAYETTE	New Drill
174	-97.0578900	30.0300050	14933402	FAYETTE	New Drill
175	-97.1107410	29.6904470	14933403	FAYETTE	New Drill
176	-97.1084320	29.6902240	14933405	FAYETTE	New Drill
177	-97.1063930	29.6902990	14933404	FAYETTE	New Drill
178	-97.3941840	29.2575270	17732681	GONZALES	Field Transfer
179	-97.3404110	29.5309450	17731049	GONZALES	Recompletion
180	-97.2271140	29.5705550	17733098	GONZALES	New Drill
181	-97.5416840	29.3508420	17733015	GONZALES	Recompletion

182	-97.5135530	29.2085800	17733460	GONZALES	New Drill
183	-97.5141100	29.2083360	17733461	GONZALES	New Drill
184	-97.5155270	29.2077000	17733463	GONZALES	New Drill
185	-97.5147330	29.2079430	17733464	GONZALES	New Drill
186	-97.2288090	29.7058250	17733467	GONZALES	New Drill
187	-97.2545800	29.3817540	17733468	GONZALES	New Drill
188	-97.2573480	29.4122270	17733469	GONZALES	New Drill
189	-97.4552090	29.2512740	17733470	GONZALES	New Drill
190	-97.6301750	29.2203040	17731780	GONZALES	Recompletion
191	-97.2460610	29.7209950	17733472	GONZALES	New Drill
192	-97.2367700	29.6175180	17733473	GONZALES	New Drill
193	-97.2375000	29.6156710	17733474	GONZALES	New Drill
194	-97.4185590	29.2544940	17733475	GONZALES	New Drill
195	-97.4178730	29.2549060	17733476	GONZALES	New Drill
196	-97.4172080	29.2553930	17733477	GONZALES	New Drill
197	-97.5591930	29.3017160	17733488	GONZALES	New Drill
198	-97.5571330	29.1652310	17733479	GONZALES	New Drill
199	-97.6631130	29.2427370	17733484	GONZALES	New Drill
200	-97.5743850	29.1542690	17733480	GONZALES	New Drill
201	-97.5564250	29.2193110	17733481	GONZALES	New Drill
202	-97.5569610	29.2188240	17733482	GONZALES	New Drill
203	-97.5574760	29.2183370	17733483	GONZALES	New Drill
204	-97.2445160	29.4808220	17733485	GONZALES	New Drill

205	-97.2428850	29.4825780	17733486	GONZALES	New Drill
206	-97.6421480	29.3227460	17733478	GONZALES	New Drill
207	-97.2673260	29.5913800	17733145	GONZALES	New Drill
208	-97.2630340	29.5955970	17733197	GONZALES	New Drill
209	-97.2716170	29.3907850	17733495	GONZALES	New Drill
210	-97.2411260	29.4797940	17733489	GONZALES	New Drill
211	-97.2391520	29.4814760	17733491	GONZALES	New Drill
212	-97.2426490	29.4481090	17733492	GONZALES	New Drill
213	-97.5875820	29.3734520	17732526	GONZALES	Recompletion
214	-97.2738490	29.3912900	17733493	GONZALES	New Drill
215	-97.2727550	29.3911400	17733494	GONZALES	New Drill
216	-97.4990470	29.2293860	17733503	GONZALES	New Drill
217	-97.4982960	29.2295920	17733504	GONZALES	New Drill
218	-97.4976740	29.2298170	17733505	GONZALES	New Drill
219	-97.4376780	29.2432230	17733490	GONZALES	New Drill
220	-97.4970300	29.2300230	17733506	GONZALES	New Drill
221	-97.5777110	29.1977730	17733497	GONZALES	New Drill
222	-97.5577770	29.1648190	17733496	GONZALES	New Drill
223	-97.2728620	29.3687960	17733234	GONZALES	New Drill
224	-97.2401170	29.4806160	17733194	GONZALES	New Drill
225	-97.5663600	29.1822430	17733501	GONZALES	New Drill
226	-97.4057490	29.2513860	17733270	GONZALES	New Drill
227	-97.4049550	29.2541940	17733269	GONZALES	New Drill

228	-97.5713380	29.1907290	17733502	GONZALES	New Drill
229	-97.6225790	29.1457610	17733507	GONZALES	New Drill
230	-97.6236950	29.1449180	17733508	GONZALES	New Drill
231	-97.2449670	29.5832260	17733510	GONZALES	New Drill
232	-97.2432290	29.5832070	17733511	GONZALES	New Drill
233	-97.5712740	29.1916100	17733512	GONZALES	New Drill
234	-97.5708660	29.1922470	17733513	GONZALES	New Drill
235	-97.4520330	29.3188740	17733517	GONZALES	New Drill
236	-97.4528270	29.3171520	17733518	GONZALES	New Drill
237	-97.4536210	29.3161790	17733519	GONZALES	New Drill
238	-97.5040680	29.3229900	17733516	GONZALES	New Drill
239	-97.4505310	29.2256220	17733520	GONZALES	New Drill
240	-97.4515830	29.2260900	17733521	GONZALES	New Drill
241	-97.5933320	29.1916470	17733529	GONZALES	New Drill
242	-97.5926670	29.1923220	17733530	GONZALES	New Drill
243	-97.5921520	29.1930900	17733531	GONZALES	New Drill
244	-97.3396380	29.3141770	17733524	GONZALES	New Drill
245	-97.3377500	29.3147200	17733522	GONZALES	New Drill
246	-97.3386940	29.3144770	17733523	GONZALES	New Drill
247	-97.4524410	29.2563850	17733525	GONZALES	New Drill
248	-97.4530200	29.2557300	17733526	GONZALES	New Drill
249	-97.4537500	29.2553740	17733527	GONZALES	New Drill
250	-97.3552160	29.3719380	17733532	GONZALES	New Drill

251	-97.3562890	29.3758640	17733535	GONZALES	New Drill
252	-97.4543720	29.2549430	17733528	GONZALES	New Drill
253	-97.6060570	29.2046470	17733539	GONZALES	New Drill
254	-97.2112140	29.4514540	17733538	GONZALES	New Drill
255	-97.2116650	29.4507440	17733537	GONZALES	New Drill
256	-97.2123510	29.4500900	17733536	GONZALES	New Drill
257	-97.3624910	29.3910090	17733533	GONZALES	New Drill
258	-97.3633920	29.3906540	17733534	GONZALES	New Drill
259	-97.5807580	29.4032920	17732965	GONZALES	Recompletion
260	-97.6040610	29.1490600	17733540	GONZALES	New Drill
261	-97.6048980	29.1485540	17733541	GONZALES	New Drill
262	-97.5847280	29.2077750	17733542	GONZALES	New Drill
263	-97.6236090	29.3927480	17732817	GONZALES	New Drill
264	-97.6236090	29.3927480	17733289	GONZALES	New Drill
265	-97.5842340	29.2084300	17733543	GONZALES	New Drill
266	-97.5837840	29.2092350	17733544	GONZALES	New Drill
267	-97.4354680	29.2660250	17733193	GONZALES	New Drill
268	-97.3608170	29.3841470	17733546	GONZALES	New Drill
269	-97.4364340	29.2649770	17733192	GONZALES	New Drill
270	-97.3635420	29.3912520	17733545	GONZALES	New Drill
271	-97.3054780	29.3510860	17733547	GONZALES	New Drill
272	-97.3048770	29.3515530	17733548	GONZALES	New Drill
273	-97.2898990	29.3410410	17733549	GONZALES	New Drill

274	-97.2894270	29.3416030	17733550	GONZALES	New Drill
275	-97.4129590	29.2746920	17733271	GONZALES	New Drill
276	-97.6943980	29.2622820	17733300	GONZALES	New Drill
277	-97.2393020	29.4479030	17733555	GONZALES	New Drill
278	-97.2501170	29.3975340	17733551	GONZALES	New Drill
279	-98.0380640	29.3980390	18733650	GUADALUPE	New Drill
280	-98.0380000	29.3956270	18733634	GUADALUPE	New Drill
281	-98.0377850	29.4014970	18733649	GUADALUPE	New Drill
282	-98.0378060	29.4024130	18733638	GUADALUPE	New Drill
283	-98.0401880	29.4001880	18733651	GUADALUPE	New Drill
284	-98.0412180	29.4002070	18733639	GUADALUPE	New Drill
285	-98.0426340	29.4002260	18733640	GUADALUPE	New Drill
286	-98.0387290	29.4027310	18733641	GUADALUPE	New Drill
287	-98.0811940	29.4247310	18733637	GUADALUPE	New Drill
288	-97.7579770	29.6973070	18733389	GUADALUPE	Recompletion
289	-97.7432350	29.6083210	18733630	GUADALUPE	Recompletion
290	-98.0152970	29.4320200	18733642	GUADALUPE	New Drill
291	-97.7503170	29.5945150	18733494	GUADALUPE	Recompletion
292	-98.1108050	29.3894570	18733643	GUADALUPE	New Drill
293	-98.1105910	29.3886160	18733644	GUADALUPE	New Drill
294	-98.1096250	29.3887660	18733645	GUADALUPE	New Drill
295	-97.7726540	29.5717680	18733646	GUADALUPE	New Drill
296	-97.7265630	29.5676810	18733647	GUADALUPE	New Drill

297	-97.8601370	29.3843530	18733648	GUADALUPE	New Drill
298	-98.0430850	29.3843910	18733653	GUADALUPE	New Drill
299	-98.0429560	29.3835490	18733652	GUADALUPE	New Drill
300	-97.0932180	30.7565610	33134900	MILAM	New Drill
301	-97.0378790	30.8097630	33134910	MILAM	New Drill
302	-97.0245540	30.8029990	33134901	MILAM	New Drill
303	-97.0030530	30.6348380	33134908	MILAM	New Drill
304	-96.9919170	30.6311080	33134912	MILAM	New Drill
305	-96.9929040	30.6322530	33134907	MILAM	New Drill
306	-97.0022160	30.6347460	33134911	MILAM	New Drill
307	-97.0040830	30.6344320	33134909	MILAM	New Drill
308	-96.9947280	30.6271750	33134916	MILAM	New Drill
309	-96.9952430	30.6276740	33134917	MILAM	New Drill
310	-96.9959510	30.6274160	33134918	MILAM	New Drill
311	-96.9058500	30.7466770	33134920	MILAM	New Drill
312	-96.9040260	30.7476540	33134919	MILAM	New Drill
313	-96.9972170	30.6267690	33134921	MILAM	New Drill
314	-96.9968730	30.6262340	33134922	MILAM	New Drill
315	-96.9977320	30.6259380	33134923	MILAM	New Drill
316	-96.9957360	30.6256980	33134924	MILAM	New Drill
317	-96.9953280	30.6252920	33134925	MILAM	New Drill
318	-96.9962940	30.6261780	33134926	MILAM	New Drill
319	-96.9987400	30.6313110	33134927	MILAM	New Drill

320	-96.9985900	30.6307390	33134928	MILAM	New Drill
321	-96.9996200	30.6311640	33134929	MILAM	New Drill
322	-97.0000700	30.6308310	33134930	MILAM	New Drill
323	-96.9995980	30.6304250	33134931	MILAM	New Drill
324	-97.0007790	30.6306280	33134932	MILAM	New Drill
325	-97.0013150	30.6276560	33134933	MILAM	New Drill
326	-97.0536720	30.7099340	33134905	MILAM	New Drill
327	-97.0009720	30.6263630	33134934	MILAM	New Drill
328	-96.6290240	30.1699240	47731023	WASHINGTON	New Drill
329	-96.7175370	30.1916440	47731024	WASHINGTON	New Drill
330	-96.7049630	30.1418700	47731025	WASHINGTON	New Drill

Disposal Wells: (Active disposal wells)

ID	X	Y	Field Name	County
1	**-97.4168**	**30.008379**	HILBIG	BASTROP
2	**-97.415577**	**30.009772**	HILBIG	BASTROP
3	**-97.481731**	**29.963997**	BATEMAN (AUSTIN CHALK)	BASTROP
4	**-97.521588**	**30.096842**	CEDAR CREEK	BASTROP
5	**-97.415412**	**30.006106**	HILBIG	BASTROP
6	**-97.412386**	**30.006218**	HILBIG	BASTROP
7	**-97.41039**	**30.006515**	HILBIG	BASTROP
8	**-97.054579**	**30.115196**	SERBIN (WILCOX)	BASTROP
9	**-97.414317**	**30.008076**	HILBIG	BASTROP

10	-97.412858	30.004193	HILBIG	BASTROP
11	-97.413834	30.010204	HILBIG	BASTROP
12	-97.508307	29.956803	BATEMAN (AUSTIN CHALK)	BASTROP
13	-97.54502	30.064018	YOAST	BASTROP
14	-97.551318	29.890782	BUCHANAN	CALDWELL
15	-97.621715	29.826448	LULING-BRANYON	CALDWELL
16	-97.612824	29.835582	LULING-BRANYON	CALDWELL
17	-97.594735	29.842823	LULING-BRANYON	CALDWELL
18	-97.702281	29.754133	LULING-BRANYON	CALDWELL
19	-97.725562	29.72572	LULING-BRANYON	CALDWELL
20	-97.718653	29.731012	LULING-BRANYON	CALDWELL
21	-97.709598	29.759275	LULING-BRANYON	CALDWELL
22	-97.700736	29.764639	LULING-BRANYON	CALDWELL
23	-97.728867	29.726969	LULING-BRANYON	CALDWELL
24	-97.690436	29.761808	LULING-BRANYON	CALDWELL
25	-97.723159	29.731366	LULING-BRANYON	CALDWELL
26	-97.577333	29.784047	SALT FLAT	CALDWELL
27	-97.618295	29.738633	SALT FLAT	CALDWELL
28	-97.592868	29.76924	SALT FLAT	CALDWELL
29	-97.635955	29.708762	SALT FLAT	CALDWELL
30	-97.629625	29.720801	SALT FLAT	CALDWELL
31	-97.567891	29.790025	TENNEY CREEK	CALDWELL
32	-97.72112	29.736975	LULING-BRANYON	CALDWELL

33	-97.6405643	29.6842762	SALT FLAT	CALDWELL
34	-97.6292795	29.6937916	SALT FLAT	CALDWELL
35			LULING-BRANYON	CALDWELL
36	-97.6714419	29.6963743	DUNLAP	CALDWELL
37	-97.7146414	29.7416108	LULING-BRANYON	CALDWELL
38	-97.6405628	29.7496488	DUNLAP	CALDWELL
39	-97.6570022	29.7360311	DUNLAP	CALDWELL
40	-97.6652194	29.6940356	SALT FLAT, WEST	CALDWELL
41	-97.6540589	29.7074551	SALT FLAT	CALDWELL
42	-97.6659842	29.7285283	DUNLAP	CALDWELL
43	-97.5277346	29.9036294	BUCHANAN	CALDWELL
44	-97.6272145	29.7224724	SALT FLAT	CALDWELL
45	-97.6007976	29.8252947	LULING-BRANYON	CALDWELL
46	-97.5537374	29.7995706	TENNEY CREEK	CALDWELL
47	-97.6209143	29.7095628	SALT FLAT	CALDWELL
48	-97.6123635	29.7609587	SALT FLAT	CALDWELL
49	-97.5656131	29.7954833	TENNEY CREEK	CALDWELL
50	-97.6701386	29.7031532	SALT FLAT, WEST	CALDWELL
51	-97.5670053	29.7889057	TENNEY CREEK	CALDWELL
52	-97.7342397	29.7132051	LULING-BRANYON	CALDWELL
53	-97.6448572	29.7830929	LULING (EDWARDS)	CALDWELL
54	-97.6295075	29.6871979	SALT FLAT	CALDWELL
55	-97.725489	29.8963987	LARREMORE	CALDWELL

56	-97.5639367	29.7980683	SALT FLAT	CALDWELL
57	-97.5639974	29.8738483	LULING-BRANYON	CALDWELL
58	-97.671815	29.7157152	DUNLAP	CALDWELL
59	-97.6289652	29.8087675	LULING-BRANYON	CALDWELL
60	-97.7298942	29.8958356	LARREMORE	CALDWELL
61	-97.5719379	29.9856708	LYTTON SPRINGS	CALDWELL
62	-97.5978533	29.9637683	LYTTON SPRINGS	CALDWELL
63	-97.6196524	29.806525	LULING-BRANYON	CALDWELL
64	-97.7029791	29.7522093	LULING-BRANYON	CALDWELL
65	-97.7084363	29.7506621	LULING-BRANYON	CALDWELL
66	-97.5810868	29.7785177	SALT FLAT	CALDWELL
67	-97.6877956	29.7644576	LULING-BRANYON	CALDWELL
68	-97.5429944	29.8973449	BUCHANAN	CALDWELL
69	-97.6284737	29.7198281	SALT FLAT	CALDWELL
70	-97.5731407	29.7908901	TENNEY CREEK	CALDWELL
71	-97.5597475	29.8793673	BUCHANAN	CALDWELL
72	-97.6984335	29.7620581	LULING-BRANYON	CALDWELL
73	-97.6365956	29.8045915	LULING-BRANYON	CALDWELL
74	-97.636455	29.7070729	SALT FLAT	CALDWELL
75	-97.7255757	29.7248204	LULING-BRANYON	CALDWELL
76	-97.7348038	29.7145348	LULING-BRANYON	CALDWELL
77	-97.686457	29.6990793	DUNLAP	CALDWELL
78	-97.5859249	29.8493026	LULING-BRANYON	CALDWELL

79	-97.6623624	29.7812903	LULING-BRANYON	CALDWELL
80	-97.6429103	29.6924132	SALT FLAT	CALDWELL
81	-97.6252755	29.8024226	LULING-BRANYON	CALDWELL
82	-97.5099024	29.9203742	DALE-MCBRIDE	CALDWELL
83	-97.6482205	29.775193	LULING-BRANYON	CALDWELL
84	-97.5127045	29.913079	DALE-MCBRIDE	CALDWELL
85	-97.7206689	29.8178341	FENTRESS (1750)	CALDWELL
86	-97.631643	29.7169568	SALT FLAT	CALDWELL
87	-97.5984665	29.7656229	SALT FLAT (EDWARDS)	CALDWELL
88	-97.6747623	29.6997651	DUNLAP	CALDWELL
89	-97.6007093	29.7452469	SALT FLAT (EDWARDS)	CALDWELL
90	-97.7368784	29.6977546	LULING-BRANYON	CALDWELL
91	-97.7350629	29.6993779	LULING-BRANYON	CALDWELL
92	-97.7392531	29.6981575	LULING-BRANYON	CALDWELL
93	-97.7375264	29.6993684	LULING-BRANYON	CALDWELL
94	-97.7360341	29.7006631	LULING-BRANYON	CALDWELL
95	-97.6101224	29.7321541	SALT FLAT (EDWARDS)	CALDWELL
96	-97.6246169	29.7288028	SALT FLAT (EDWARDS)	CALDWELL
97	-97.6357522	29.701244	SALT FLAT (EDWARDS)	CALDWELL
98	-97.5227165	29.915815	DALE-MCBRIDE	CALDWELL
99	-97.6131102	29.8176562	LULING-BRANYON	CALDWELL
100	-97.5241434	29.9123345	DALE-MCBRIDE	CALDWELL
101	-97.630453	29.9669866	DRUMMOND (EDWARDS 1800)	CALDWELL

102	-97.5861493	29.7675982	SALT FLAT (EDWARDS)	CALDWELL
103	-97.6164497	29.7255254	SALT FLAT (EDWARDS)	CALDWELL
104	-97.5856899	29.7794303	SALT FLAT (EDWARDS)	CALDWELL
105	-97.6305917	29.7072055	SALT FLAT (EDWARDS)	CALDWELL
106	-97.5946667	29.755617	SALT FLAT (EDWARDS)	CALDWELL
107	-97.6404622	29.6950767	SALT FLAT (EDWARDS)	CALDWELL
108	-97.7290784	29.7016732	LULING-BRANYON	CALDWELL
109	-97.7338003	29.8921958	LARREMORE	CALDWELL
110	-97.6019788	29.7440872	SALT FLAT (EDWARDS)	CALDWELL
111	-97.673361	29.697984	SALT FLAT, WEST	CALDWELL
112	-97.63275	29.8060361		CALDWELL
113	-97.6702098	29.7824104		CALDWELL
114	-97.6308268	29.8000036		CALDWELL
115	-97.6188968	29.7383506	SALT FLAT (EDWARDS)	CALDWELL
116	-96.932243	30.164125	GIDDINGS (BUDA)	LEE
117	-96.973592	30.1885	GIDDINGS (AUSTIN CHALK-3)	LEE
118	-96.92205	30.526926	NOACK COW HERD (3460)	LEE
119	-96.817831	30.266165	GIDDINGS (AUSTIN CHALK, GAS)	LEE
120	-96.571254	30.381325	GIDDINGS (AUSTIN CHALK-3)	BURLESON
121	-96.574518	30.415229	CALDWELL (AUSTIN CHALK)	BURLESON
122	-96.539768	30.41475	GIDDINGS (AUSTIN CHALK-3)	BURLESON
123	-96.581449	30.379434	GIDDINGS (WILCOX)	BURLESON
124	-96.560025	30.397846	GIDDINGS (AUSTIN CHALK-3)	BURLESON

125	-96.554136	30.389965	GIDDINGS (AUSTIN CHALK-3)	BURLESON
126	-96.337468	30.377543	JERRY'S QUARTERS (A C 11900)	BURLESON
127	-96.928294	30.570814	BURMIL (W-2 SAND)	BURLESON
128	-96.618718	30.702712	GIDDINGS (AUSTIN CHALK-3)	BURLESON
129	-97.130122	29.841009	GIDDINGS (AUSTIN CHALK-3)	FAYETTE
130	-96.834414	30.064494	GINI (WILCOX)	FAYETTE
131	-96.826265	30.083836	GINI (WILCOX)	FAYETTE
132	-96.832889	30.068869	GINI (WILCOX)	FAYETTE
133	-96.989527	29.938434	GIDDINGS (AUSTIN CHALK-3)	FAYETTE
134	-96.839163	30.016372	GIDDINGS (AUSTIN CHALK-3)	FAYETTE
135	-96.858554	29.990143	JORDAN CREEK (WILCOX 5700)	FAYETTE
136	-96.807167	30.125853	STEPHANIE (WILCOX)	FAYETTE
137	-96.828649	30.10345	GIDDINGS (AUSTIN CHALK-3)	FAYETTE
138	-96.899739	30.090144	GIDDINGS (NORTH EDWARDS)	FAYETTE
139	-96.837257	30.063064	GINI (WILCOX)	FAYETTE
140	-96.951731	29.924009	GIDDINGS (AUSTIN CHALK-3)	FAYETTE
141	-97.086561	29.701274	GIDDINGS (AUSTIN CHALK-3)	FAYETTE
142	-97.540974	29.171429	DUBOSE (EDWARDS -A-)	GONZALES
143	-97.461593	29.444501	MAG (BUDA)	GONZALES
144	-97.629743	29.263289	FIRST SHOT (AUSTIN CHALK)	GONZALES
145	-97.267723	29.666755	WAELDER, SOUTH (ESCONDIDO)	GONZALES
146	-97.510553	29.31698	PILGRIM (AUSTIN CHALK)	GONZALES
147	-97.35416	29.608153		GONZALES

148	-97.267434	29.463838	AUSTIN PIERCE (AUSTIN CHALK)	GONZALES
149	-97.387082	29.300755	FULCHER (EDWARDS A)	GONZALES
150	-97.396383	29.307472	EAGLEVILLE (EAGLE FORD-1)	GONZALES
151	-97.396945	29.432949	PILGRIM (AUSTIN CHALK)	GONZALES
152	-97.433573	29.456691	EAGLEVILLE (EAGLE FORD-1)	GONZALES
153	-97.375486	29.326734	EAGLEVILLE (EAGLE FORD-1)	GONZALES
154	-97.732972	29.340333	NIXON	GONZALES
155	-97.535647	29.224712	EAGLEVILLE (EAGLE FORD-1)	GONZALES
156	-97.379098	29.527845	PEACH CREEK (AUSTIN CHALK)	GONZALES
157	-97.762095	29.297491	NIXON	GONZALES
158	-97.796432	29.55068	DARST CREEK (BUDA)	GUADALUPE
159	-97.719664	29.617114	DARST CREEK (BUDA)	GUADALUPE
160	-97.750047	29.595626	DARST CREEK (BUDA)	GUADALUPE
161	-97.750374	29.595254	DARST CREEK (BUDA)	GUADALUPE
162	-97.749549	29.596024	DARST CREEK (BUDA)	GUADALUPE
163	-97.765788	29.582037	DARST CREEK (EDWARDS)	GUADALUPE
164	-97.735843	29.610796	DARST CREEK (EDWARDS)	GUADALUPE
165	-97.738832	29.608547	DARST CREEK (EDWARDS)	GUADALUPE
166	-97.746714	29.60362	DARST CREEK (EDWARDS)	GUADALUPE
167	-97.738404	29.610372	DARST CREEK (EDWARDS)	GUADALUPE
168	-97.709467	29.681041	DUNLAP	GUADALUPE
169	-97.731143	29.656708	DUNLAP	GUADALUPE
170	-97.720996	29.667543	DUNLAP	GUADALUPE

171	-97.754274	29.703531	LULING-BRANYON	GUADALUPE
172	-97.757917	29.689004	LULING-BRANYON	GUADALUPE
173	-97.750194	29.698208	LULING-BRANYON	GUADALUPE
174	-97.743147	29.703547	LULING-BRANYON	GUADALUPE
175	-97.760727	29.68908	LULING-BRANYON	GUADALUPE
176	-97.754989	29.704808	LULING-BRANYON	GUADALUPE
177	-97.7569	29.567365	DARST CREEK (EDWARDS)	GUADALUPE
178	-97.746344	29.603596	DARST CREEK (EDWARDS)	GUADALUPE
179	-97.744464	29.603925	DARST CREEK (EDWARDS)	GUADALUPE
180	-97.736784	29.612474	DARST CREEK (EDWARDS)	GUADALUPE
181	-97.73258	29.611078	DARST CREEK (EDWARDS)	GUADALUPE
182	-97.786773	29.558398	DARST CREEK (EDWARDS)	GUADALUPE
183	-97.752263	29.582618	DARST CREEK (BUDA)	GUADALUPE
184	-97.77391	29.56974	DARST CREEK (EDWARDS)	GUADALUPE
185	-97.761441	29.688941	LULING-BRANYON	GUADALUPE
186	-97.69134	29.611094	KENS (SERPENTINE)	GUADALUPE
187	-97.653833	29.665106	SALT FLAT	GUADALUPE
188	-97.770973	29.573311	DARST CREEK (BUDA)	GUADALUPE
189	-98.02625	29.409987	LA VERNIA (AUSTIN CHALK)	GUADALUPE
190	-97.749596	29.703977	LULING-BRANYON	GUADALUPE
191	-97.750098	29.703251	LULING-BRANYON	GUADALUPE
192	-97.739009	29.686618	SPILLER	GUADALUPE
193	-97.740215	29.684996	SPILLER	GUADALUPE

194	-97.749771	29.706314	LULING-BRANYON	GUADALUPE
195	-97.752457	29.703039	LULING-BRANYON	GUADALUPE
196	-97.748909	29.700394	LULING-BRANYON	GUADALUPE
197	-97.739132	29.688939	SPILLER	GUADALUPE
198	-97.75731	29.692582	LULING-BRANYON	GUADALUPE
199	-97.744836	29.693427	LULING-BRANYON	GUADALUPE
200	-97.742972	29.683032	SPILLER	GUADALUPE
201	-97.745584	29.681463	SPILLER	GUADALUPE
202	-97.747532	29.681144	SPILLER	GUADALUPE
203	-97.759059	29.5863	DARST CREEK (EDWARDS)	GUADALUPE
204	-97.747117	29.697361	LULING-BRANYON	GUADALUPE
205	-97.746972	29.595352	DARST CREEK (EDWARDS)	GUADALUPE
206	-97.859808	29.383688	NIXON	GUADALUPE
207	-97.818577	29.652262	KINGSBURY (BUDA LIME)	GUADALUPE
208	-97.72842	29.659081	DUNLAP	GUADALUPE
209	-97.723746	29.661919	DUNLAP	GUADALUPE
210	-97.75272	29.689495	LULING-BRANYON	GUADALUPE
211	-97.73663	29.665637	SPILLER	GUADALUPE
212	-96.864012	30.617106	MILBUR, N. (WILCOX 2660)	MILAM
213	-96.842527	30.709645	MILANO, SOUTH (AUSTIN CHALK)	MILAM
214	-96.96903	30.605972	BULLOH (NAVARRO)	MILAM
215	-96.862504	30.62283	PECAN GAP (5050)	MILAM
216	-96.895199	30.644159	MIDWAY (2300 OIL)	MILAM

217	-97.021059	30.720961	MINERVA-ROCKDALE	MILAM
218	-97.02659	30.74966	MINERVA-ROCKDALE	MILAM
219	-97.02556	30.74912	MINERVA-ROCKDALE	MILAM
220	-97.02978	30.75045	MINERVA-ROCKDALE	MILAM
221	-97.02861	30.75094	MINERVA-ROCKDALE	MILAM
222	-97.031727	30.746751	MINERVA-ROCKDALE	MILAM
223	-97.032104	30.745067	MINERVA-ROCKDALE	MILAM
224	-97.032345	30.7405	MINERVA-ROCKDALE	MILAM
225	-97.030242	30.734718	MINERVA-ROCKDALE	MILAM
226	-97.029229	30.749038	MINERVA-ROCKDALE	MILAM
227	-97.015582	30.737807	MINERVA-ROCKDALE	MILAM
228	-97.023993	30.746108	MINERVA-ROCKDALE	MILAM
229	-97.02065	30.74108	MINERVA-ROCKDALE	MILAM
230	-97.02154	30.7419	MINERVA-ROCKDALE	MILAM
231	-97.018353	30.737909	MINERVA-ROCKDALE	MILAM
232	-97.018553	30.736926	MINERVA-ROCKDALE	MILAM
233	-97.01874	30.735716	MINERVA-ROCKDALE	MILAM
234	-97.018902	30.734561	MINERVA-ROCKDALE	MILAM
235	-97.019864	30.747643	MINERVA-ROCKDALE	MILAM
236	-97.019782	30.735472	MINERVA-ROCKDALE	MILAM
237	-97.01897	30.73975	MINERVA-ROCKDALE	MILAM
238	-97.017129	30.745953	MINERVA-ROCKDALE	MILAM
239	-97.014155	30.744979	MINERVA-ROCKDALE	MILAM

240	-97.017684	30.724145	MINERVA-ROCKDALE	MILAM
241	-97.019844	30.725484	MINERVA-ROCKDALE	MILAM
242	-97.02203	30.72695	MINERVA-ROCKDALE	MILAM
243	-97.02008	30.73678	MINERVA-ROCKDALE	MILAM
244	-97.02223	30.73389	MINERVA-ROCKDALE	MILAM
245	-97.025345	30.730304	MINERVA-ROCKDALE	MILAM
246	-97.020375	30.736039	MINERVA-ROCKDALE	MILAM
247	-97.018338	30.739097	MINERVA-ROCKDALE	MILAM
248	-97.016184	30.724075	MINERVA-ROCKDALE	MILAM
249	-97.017695	30.720431	MINERVA-ROCKDALE	MILAM
250	-97.018948	30.721488	MINERVA-ROCKDALE	MILAM
251	-97.017668	30.719255	MINERVA-ROCKDALE	MILAM
252	-97.020294	30.716857	MINERVA-ROCKDALE	MILAM
253	-97.020951	30.716257	MINERVA-ROCKDALE	MILAM
254	-97.020348	30.719209	MINERVA-ROCKDALE	MILAM
255	-97.022372	30.719762	MINERVA-ROCKDALE	MILAM
256	-97.02478	30.717564	MINERVA-ROCKDALE	MILAM
257	-97.022774	30.717794	MINERVA-ROCKDALE	MILAM
258	-97.01608	30.72037	MINERVA-ROCKDALE	MILAM
259	-97.029055	30.727504	MINERVA-ROCKDALE	MILAM
260	-97.031585	30.733044	MINERVA-ROCKDALE	MILAM
261	-97.031655	30.734264	MINERVA-ROCKDALE	MILAM
262	-97.02676	30.74106	MINERVA-ROCKDALE	MILAM

263	-97.0277	30.74	MINERVA-ROCKDALE	MILAM
264	-97.02884	30.73957	MINERVA-ROCKDALE	MILAM
265	-97.02868	30.7385	MINERVA-ROCKDALE	MILAM
266	-97.02951	30.73772	MINERVA-ROCKDALE	MILAM
267	-97.02857	30.73695	MINERVA-ROCKDALE	MILAM
268	-97.02734	30.73654	MINERVA-ROCKDALE	MILAM
269	-97.02761	30.73541	MINERVA-ROCKDALE	MILAM
270	-97.02426	30.74426	MINERVA-ROCKDALE	MILAM
271	-97.026256	30.739928	MINERVA-ROCKDALE	MILAM
272	-97.025428	30.741154	MINERVA-ROCKDALE	MILAM
273	-97.024667	30.742009	MINERVA-ROCKDALE	MILAM
274	-97.029543	30.73373	MINERVA-ROCKDALE	MILAM
275	-97.028944	30.734729	MINERVA-ROCKDALE	MILAM
276	-97.02195	30.73557	MINERVA-ROCKDALE	MILAM
277	-97.016758	30.738047	MINERVA-ROCKDALE	MILAM
278	-97.01945	30.75384	MINERVA-ROCKDALE	MILAM
279	-97.014257	30.744053	MINERVA-ROCKDALE	MILAM
280	-97.020048	30.741515	MINERVA-ROCKDALE	MILAM
281	-97.018954	30.741948	MINERVA-ROCKDALE	MILAM
282	-97.028025	30.727304	MINERVA-ROCKDALE	MILAM
283	-97.028155	30.726464	MINERVA-ROCKDALE	MILAM
284	-97.009374	30.723325	MINERVA-ROCKDALE	MILAM
285	-97.009464	30.720665	MINERVA-ROCKDALE	MILAM

286	-97.007604	30.721195	MINERVA-ROCKDALE	MILAM
287	-97.006514	30.721115	MINERVA-ROCKDALE	MILAM
288	-97.004734	30.721535	MINERVA-ROCKDALE	MILAM
289	-97.006184	30.717515	MINERVA-ROCKDALE	MILAM
290	-97.005214	30.717215	MINERVA-ROCKDALE	MILAM
291	-97.021012	30.764065	MINERVA-ROCKDALE	MILAM
292	-97.021047	30.762415	MINERVA-ROCKDALE	MILAM
293	-97.010924	30.749863	MINERVA-ROCKDALE	MILAM
294	-97.018254	30.753973	MINERVA-ROCKDALE	MILAM
295	-97.019656	30.755356	MINERVA-ROCKDALE	MILAM
296	-97.01471	30.75387	MINERVA-ROCKDALE	MILAM
297	-97.01481	30.75292	MINERVA-ROCKDALE	MILAM
298	-97.01527	30.741862	MINERVA-ROCKDALE	MILAM
299	-96.99224	30.626453	MINERVA-ROCKDALE	MILAM
300	-97.011788	30.741385	MINERVA-ROCKDALE	MILAM
301	-97.012655	30.743123	MINERVA-ROCKDALE	MILAM
302	-97.011981	30.742579	MINERVA-ROCKDALE	MILAM
303	-97.009425	30.746294	MINERVA-ROCKDALE	MILAM
304	-97.010742	30.746062	MINERVA-ROCKDALE	MILAM
305	-97.013188	30.73666	MINERVA-ROCKDALE	MILAM
306	-97.011294	30.741974	MINERVA-ROCKDALE	MILAM
307	-97.02481	30.74865	MINERVA-ROCKDALE	MILAM
308	-97.022889	30.742147	MINERVA-ROCKDALE	MILAM

309	-97.021614	30.738444	MINERVA-ROCKDALE	MILAM
310	-97.016734	30.721895	MINERVA-ROCKDALE	MILAM
311	-97.018684	30.726344	MINERVA-ROCKDALE	MILAM
312	-97.02112	30.72664	MINERVA-ROCKDALE	MILAM
313	-97.02282	30.72761	MINERVA-ROCKDALE	MILAM
314	-97.02216	30.73107	MINERVA-ROCKDALE	MILAM
315	-97.02094	30.73524	MINERVA-ROCKDALE	MILAM
316	-96.398339	30.310837	CLAY CREEK	WASHINGTON
317	-96.410269	30.300228	CLAY CREEK	WASHINGTON

Bibliography

Data Sources:

Hydraulic Fracturing water volumes [Excel]. FracFocus.org

Injection Well Permits [Excel]. (2015). Austin, Texas: Railroad commission of Texas online system. W-1 drilling permit application query. [April 1st 2015].

Oil Well Permits: Final Approval Date 06/01/2014 to 08/31/2014 [Excel]. (2015). Austin, Texas: Railroad commission of Texas online system. W-1 drilling permit application query. [September 22nd 2015].

Oil Well Permits: Final Approval Date 09/01/2014 to 11/30/2014 [Excel]. (2015). Austin, Texas: Railroad commission of Texas online system. W-1 drilling permit application query. [September 22nd 2015].

Public Water System Wells & Surface Water Intakes [Shapefile]. (2012). Austin, Texas: Texas Commission on Environmental Quality. Available FTP: http://www.tceq.state.tx.us/assets/public/gis/exports/pws_wells_intakes.zip [September 22nd 2015].

StartMap_County_Poly: Texas Counties Boundaries/ [Shapefile] (2015) Austin, Texas: Texas Natural Resources Information System. Available FTP: https://tnris-datadownload.s3.amazonaws.com/d/stratmap-bnd/state/tx/stratmap-bnd_tx.zip

TxDOT Quarries [Shapefile]. (2015). Ausin, Texas: Texas Department of Transportation. Project Advisor: Rhonda Roundy. [June 15th 2015].

TxDOT roadway network [Shapefile]. (2015). Ausin, Texas: Center of Transportation Research. Researcher: Katie Kam.. [July 10th 2015].

Figure Sources:

TCEQ. Texas Commission on Environmental Quality: Air Quality *Active Oil and Gas Wells,* January 2014.

TCEQ. Texas Commission on Environmental Quality: Air Quality *Eagle Ford Shale Geological Area,* 2015.

Sources:

Abramzon, Shmuel, Constantine Samaras, Aimee Curtright, Aviva Litovitz, and Nicholas Burger. "Estimating the consumptive use costs of shale natural gas extraction on Pennsylvania roadways." *Journal of Infrastructure Systems*, 2014.

ArcGIS Resource Center, Professional Library; Geoprocessing tool reference, Spatial Analyst toolbox; Density toolset concepts. 2011.

ATRI, America Transportation Research institute. *Cost of Congestion to the Trucking Industry.* 2014.

Cambridge Systematics, Traffic Congestion and Reliability: Linking Solutions to Problems. *Federal Highway Administration report*. 2004.

Cambridge Systematics, Traffic Data Collection, Analysis, and Forecasting for Mechanistic Pavement Design. *NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM; NCHRP REPORT 538.* 2005.

FHWA, Federal Highway Administration, *Comprehensive Truck Size and Weight study Vol. 3* (See figure III-6), 2000.

FHWA, Federal Highway Administration; Freight Management and Operations. *Commercial Vehicle Size and Weight Program.* Dec 2013.

FHWA, Federal Highway Administration; Office of Highway Policy Information. *VMT-422 Public Road Mileage, Lane Miles and VMT 1980-2008.* 2008.

Galehouse, Larry. Federal Highway Administration*;* Pavement Preservation Compendium Michigan Department of Transportation's "Mix of Fixes" Program*. Sept 2003*

Hajek, J. J., O. J. Selezneva, G. Mladenovic, and Y. J. Jiang. "Estimating Cumulative Traffic Loads," Volume II: Traffic Data Assessment and Axle Load Projection for the Sites with Acceptable Axle Weight Data, Final Report for Phase 2. No. FHWA-RD-03-094, 2005.

Holland, Howard, ed. "Maintenance Management Manual." *Texas Department of Transportation* 1 July 2014.

Jaller, Miguel., Sanchez-Diaz, Ivan., Holguin-veras, Jose., Lawson, Catherin. AREA BASED FREIGHT TRIP GENERATION MODELS. *Transportation Research Bureau Annual Meeting*. 2014.

Kawa, Izydor, Zhanmin Zhang, and W. Ronald Hudson. "EVALUATION OF THE AASHTO 18-KIP LOAD EQUIVALENCY CONCEPT." Report FHWA/TX- 05/0-1713-1. Texas Department of Transportation,May 1998.

Kelso, Matt. “Over 1.1 Million Active Oil and Gas Wells in the US” *Fractrack Alliance*. Mar. 4 2-14

Kubas. Andrew., Vachal, Kimberly. “Impact of Energy Sector Growth on Perceived Transportation Safety in the Seventeen-County Oil Region of Western North Dakota: A Follow-Up Study” *Rural Transportation Safety and Security Center: North Dakota State University* 2014.

McCromach, Edward., Ta, Chilan., Bassok, Alon., Fishkin, Emily. TRUCK TRIP GENERATION BY GROCERY STORES; *Washington State Department of Transportation.* 2010.

Montgomery, Carl T.; Smith, Michael B. Hydraulic fracturing. History of an enduring technology. *Society of Petroleum Engineers*, pp. 26–41, 2012.

Motuba, Diomo N., A TRUCK-BASED URBAN PLANNING MODEL: TYPOLOGY, MODEL DEVELOPMENT AND VALIDATION; *North Dakota State University*. 2009.

Neustaedter, Craig, and Linda Fuller. *“Truck Trip Generation Study”.* City of Fontana, 2003

New York State Department Environmental Conservation. “*Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining*” 1998.

Nixon, Tom. Boston Central Transportation Planning. *Truck Trip Generation Rates by Land Use in the Central Artery/Tunnel Project Study Area.* September 1993

Osegueda, R. A., Ashur, S., Melchor-Lucer, O., Carrasco, C.J. and Garcia-Diaz, A. Development of Automated Routing of Overweight/Oversize Vehicles System for Houston District; *Texas Department of Transportation* 1997.

Prozzi, J. P., J. A. Prozzi, S. Grebenschikov, and A. Banerjee. Impacts of Energy Developments on the Texas Transportation System. Report FHWA/TX-11/0-6513-1. Texas Department of Transportation, Austin, 2011.

Quiroga, Cesar, Fernando, Emmanuel, Oh, Jeongho. (2012). "Energy Developments and the Transportation Infrastructure in Texas: Impacts and Strategies," No. FHWA/TX-12/0-6498-1, 2012.

Reimer, Mark, Jonathan Regehr. "Framework for Characterizing Truck Traffic Related to Petroleum Well Development and Production in Unconventional Shale Plays." *Transportation Research Record: Journal of the Transportation Research Board* 2410, pp. 1-9, 2014.

Sianipar, C. P., Dowaki, K., "Eco-burden in pavement maintenance: Effects from excess traffic growth and overload." *Sustainable Cities and Society* 12, pp.31-45, 2014.

Tadi, Ramakrishna., Balbach, Paul. Truck Trip Genemtion Characteristics of Nonresidential land Uses. *Institute of Transportation Engineers Journal* pp. 43-47. 1994.

Tiemann, Mary, and Adam Vann. "Hydraulic Fracturing and Safe Drinking Water Act Regulatory Issues." Congressional Research Service, Report 41760, 2013.

Tirado, C., Q. Yan, C. Carrasco, and R. Osegueda. "A GIS-BASED ALGORITIIM FOR ESTIMATING DAMAGE DUE TO SUPERHEAVY LOADS." Report FHWA/TX- 05/9-1502-01-6. Texas Department of Transportation, Mar. 2006.

TRB, Transportation Research Bureau. Special Report 288; *METROPOLITAN TRAVEL FORECASTING Current Practice and Future Direction.* 2007.

US Census, Characteristics of New Housing; Lot Size of New Single-Family Houses Sold Excluding Condominiums; *US Census*. 2010.

US Census, New Census Bureau Population Estimates Reveal Metro Areas and Counties that Propelled Growth in Florida and the Nation; *US Census. Release Number: CB15-56.* 2015.

US Dept. of Energy, *How is shale gas produced?,* Apr. 2013.

UDOT, Utah Department of Transportation. *PAVEMENT MANAGEMENT AND PAVEMENT DESIGN MANUAL*, 2008, page 69.

USDOT, United States Dept. of Transportation; Bureau of Transportation Statistics publications; *Freight Shipments in America*; 2004.

USDOT, United States Dept. of Transportation; Bureau of Transportation Statistics publications; Government Transportation Financial Statistics; *Capital, and Operation & Maintenance Expenditure*; 2014; Table 21-A

USDOT, United States Dept. of Transportation; Bureau of Transportation Statistics publications; State Transportation Statistics; *Highway Vehicle-Miles Traveled (VMT): 2007, 2012* 2014; Table 5-3

USEIA, U.S. Energy Information Administration. Independent Statistics & Analysis; *Top 100 U.S Oil and Gas Fields*. Mar. 2015